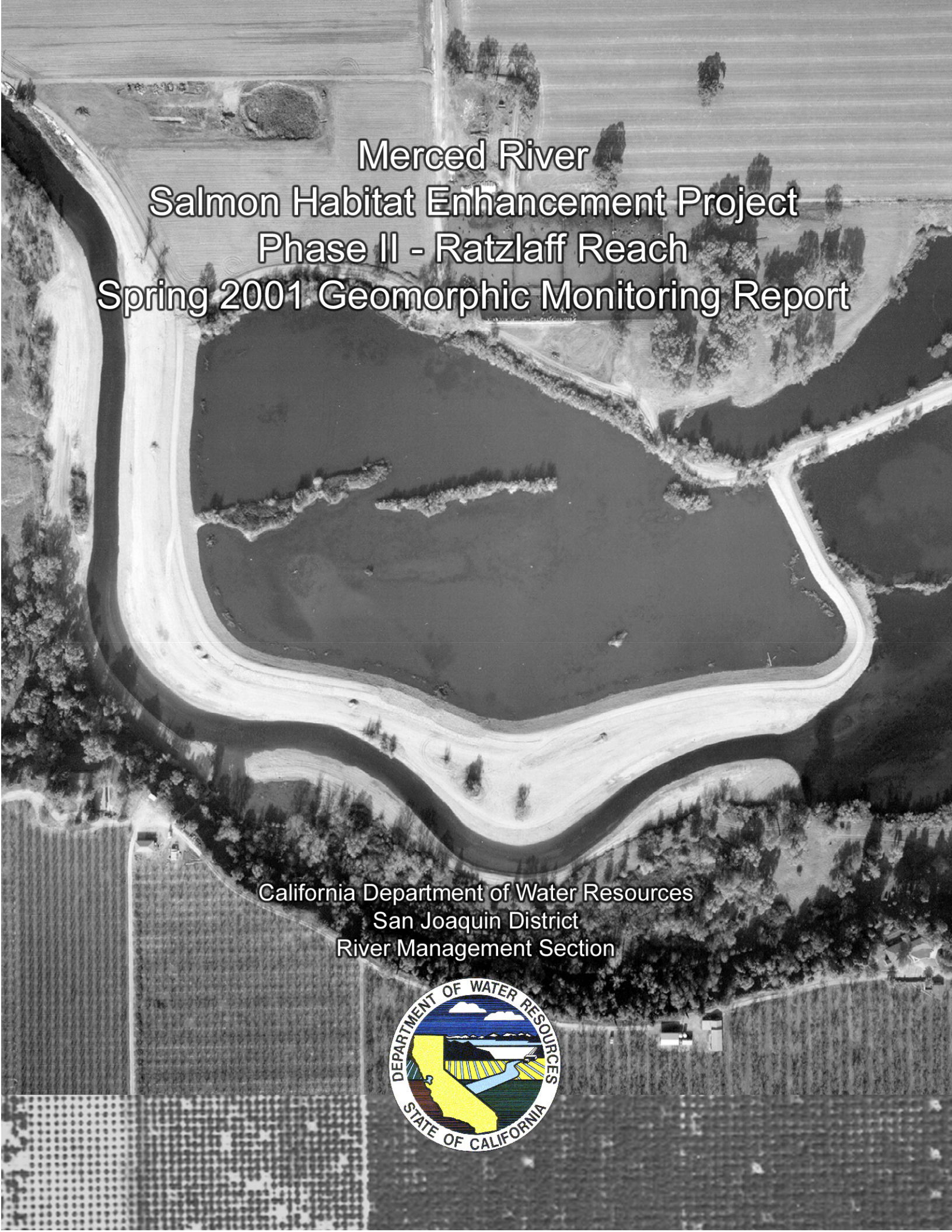

Merced River
Salmon Habitat Enhancement Project
Phase II - Ratzlaff Reach
Spring 2001 Geomorphic Monitoring Report

California Department of Water Resources
San Joaquin District
River Management Section

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River Management Section

March 27, 2002

A Joint Project by:
California Department of Water Resources
California Department of Fish and Game

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U.S. Fish and Wildlife Service / Anadromous Fish Restoration Program
U.S. Bureau of Reclamation / CALFED Bay Delta Program

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Introduction

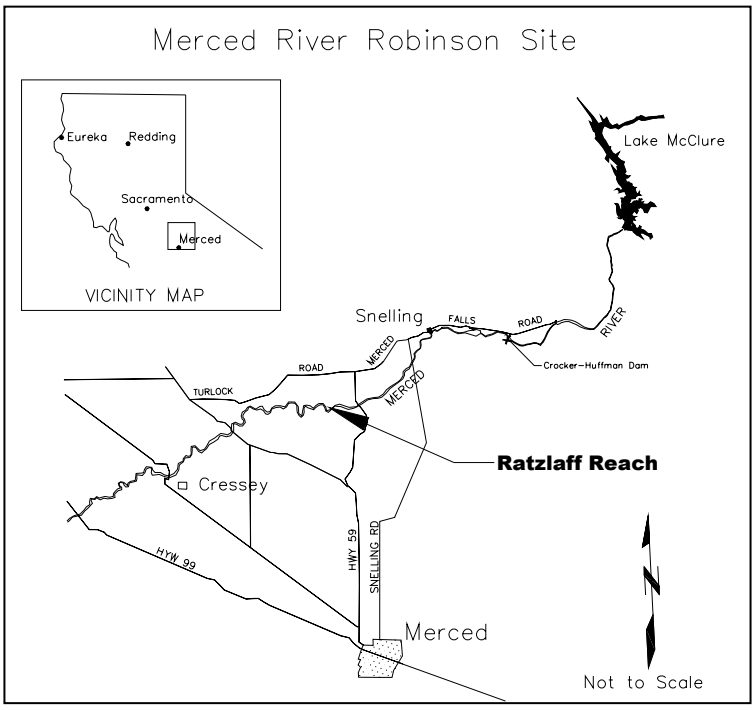
The Merced River, which flows from Yosemite National Park to the San Joaquin River, has a wide range of uses including agriculture, urban, recreational, and environmental. Many of these uses restrict the others by changing the timing, duration, frequency, and volume of river flow. Several of these uses remove or entrain material, which leads to alteration of the contents of the dissolved, suspended, and bedload materials. Some uses change river characteristics such as sinuosity, riffle/pool sequences, entrenchment, and floodplain inundation. A desire to advance the river's restoration while maintaining its uses has prompted many studies and projects such as the "Merced River Salmon Habitat Enhancement Project", formerly known as the "Robinson/Gallo Project." Phase II of this project, the Ratzlaff Reach, introduced changes in the river characteristics to create a dynamic channel and floodplain at existing flows that salmon can use for spawning and maturing processes.

Monitoring and reporting the monitoring results are required as the next steps in this project. The monitoring data establish a description of the Ratzlaff Reach at a specific time. This report presents, reviews, and applies geomorphic data in an evaluation of the effectiveness of the physical design assumptions and success of the project.

Project Description

The Ratzlaff Reach is on the Merced River between river miles 40.0 and 40.5, approximately 6 miles southwest of the town of Snelling (Figure 1). Abandoned aggregate mining ponds separated from the main channel by low narrow berms are characteristic of this reach. These berms became islands when portions of them washed out in high flows that allowed the river to entrain the ponds and divert most of its flow through the ponds (Figure 2, Before). The remaining channel was encroached by vegetation and had little effective floodplain.

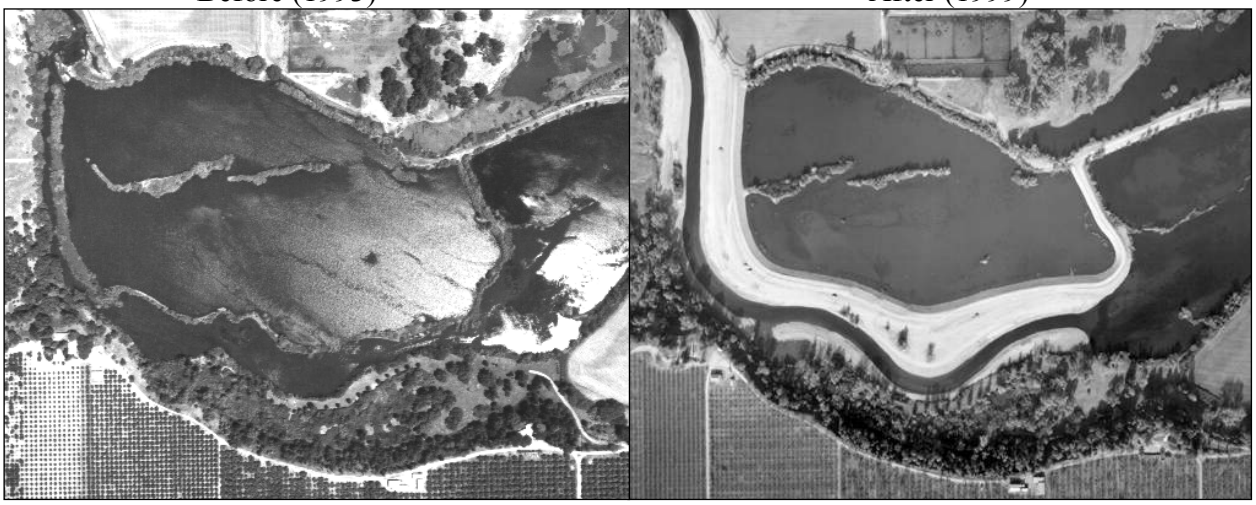
Figure 1 Project Location Map



Construction of the project established a new channel roughly following a historic channel, created a floodplain by filling in part of the pond, and isolated the remaining section of pond from the channel and floodplain by constructing a berm (Figure 2). The channel and floodplain design provided for meander and habitat diversity by varying the channel slope and cross section shape while following an alignment that approximates a channel defined by natural processes.

Figure 2 Ratzlaff Reach Before and After Phase II

Before (1993) After (1999)



Monitoring Procedure Overview

The methods used to collect and analyze data include cross section surveys, pebble counts, bulk samples, tracer gravel experiments, and HEC-RAS modeling. Cross section surveys define the geometry of the channel and its floodplain. They can also be used to define a profile of the reach so that average slopes and relative locations of pool/riffle/run sequences can be identified. Comparison with subsequent surveys can reveal vertical or lateral movements of the channel and estimate changes in stream and floodplain alluvium storage. Pebble counts and bulk samples indicate the coarseness and grading of the bed materials when used to relate the size of the material to the rate of occurrence. Tracer gravel experiments identify flows that will move specific sizes of gravel and allow the determination of attributes that are used in sediment transport models. Using models to back-calculate modeling assumptions provides a check on the design assumptions. The HEC-RAS model predicts flow depths, slopes, velocities, and shears, which aid in sediment transport modeling, checking the design, and monitoring ongoing processes.

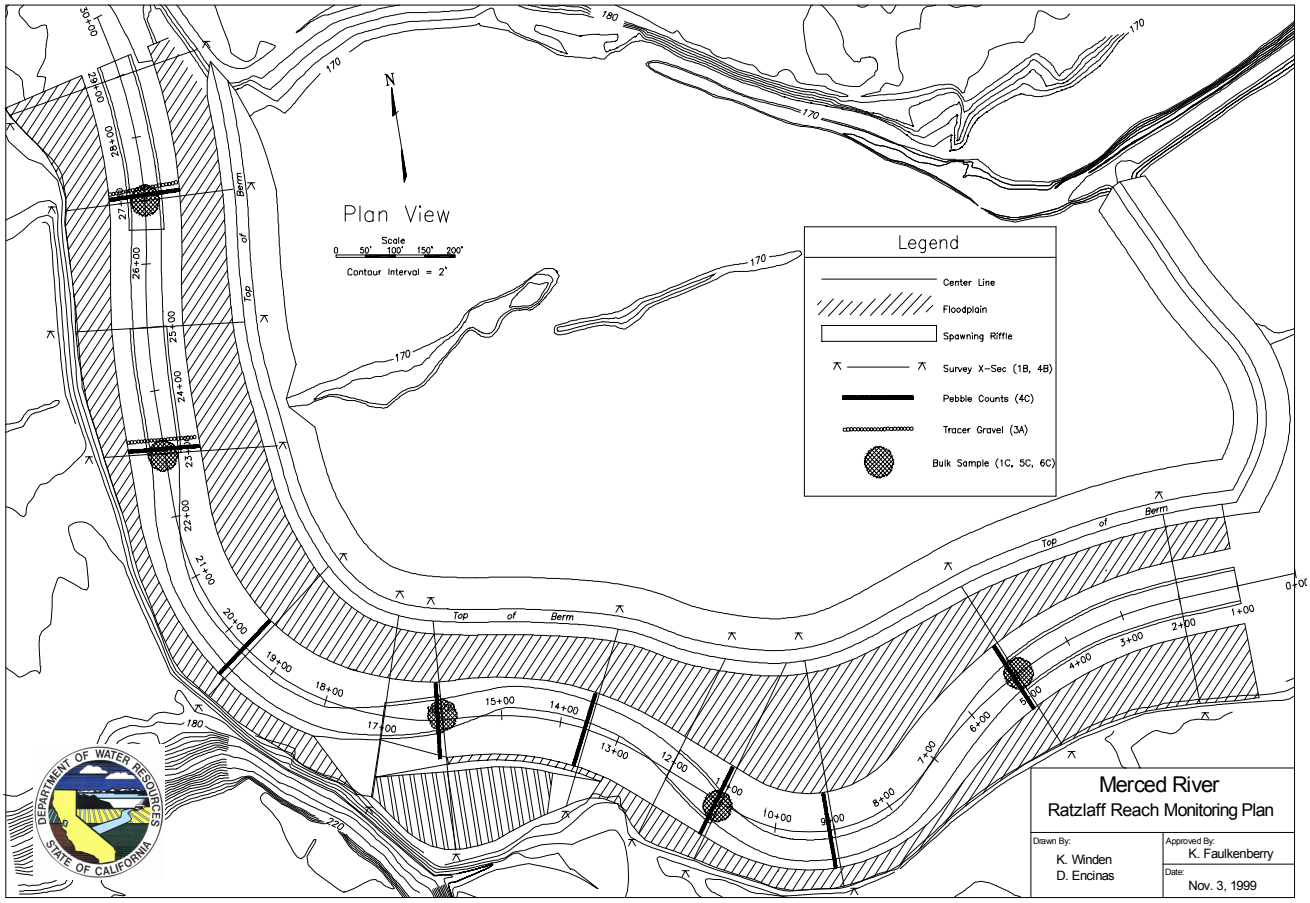
The monitoring schedule reflects the anticipated return interval for 2000 cfs flows and the maximum elapsed time before monitoring (Figure 3). This schedule provides a maximum of three years between monitoring activities when flows do not exceed 2,000 cfs and there is no movement of the tracer gravel. If there is tracer gravel movement, or the flows exceed 2,000 cfs, additional surveys and geomorphic monitoring will be performed.

Figure 3 Monitoring Schedule

	As Built Survey	Topo Survey	Cross Section Survey	Pebble Counts	Tracer Gravel	Bulk Samples	Water Elevation
1999	▨			▨		▨	
2000			▨		▨		▨
2001				▨			
2002			■	■	■		
2003							
2004		■	■	■	■	■	■
2005							
2006			■	■	■		
2007							
2008							
2009		■	■	■	■	■	
2010							
2011			■	■	■		
2012							
2013							
2014		■	■	■	■	■	■
2015							

▨ Completed ■ Scheduled according to return period for predetermined flows

Figure 4 Monitoring Locations



Bulk samples and tracer gravel studies will be conducted in riffle sections, while pebble counts and cross section surveys will take place in both riffle and pool sections (Figure 4). Monitoring in the riffle sections is tailored to higher slopes and velocities where sediment transport is likely. Pool sections typically have lower slopes, velocities, and shears and are monitored for alluvial storage.

Fall of 1999 Baseline Monitoring

Baseline monitoring establishes a post-construction description of the reach from the as-built survey, pebble counts, and bulk samples. This set of data establishes a datum, or reference, with which to compare later monitoring data. Additionally, the data can be used in conjunction with water elevation data to calibrate the hydraulic model.

As-Built Survey

The as-built cross sectional surveys were used to develop a topographic map (Appendix A). Cross sections were surveyed every 100 feet perpendicular to the centerline of the channel and corresponded to the design stationing. Looking downstream, the cross sections ranged from the left edge of the floodplain, where construction met existing ground, across the channel to the right (pond) side of the berm.

Thalweg, waterline, top of bank, and grade break points describe the current channel alignment. Thalweg elevations were determined at each cross section and used to develop a profile of the project (Appendix A). Waterline, top of bank, and grade break points were used to indicate changes in the alignment and alluvial storage in the channel by comparing baseline with later surveys (Appendix B).

Pebble Counts

Pebble counts were used to establish gradation curves at specific cross sections to characterize the bed. The pebble count procedure measures the intermediate axis of individual surface particles sampled randomly along a cross section (Wolman 1954). Approximately 100 samples per cross section were measured and plotted in the gradation curves shown in Appendix D. Table 1 shows the D_{50} and D_{84} of these baseline measurements taken in November 1999.

Table 1 Particle Sizes from Nov 1999 pebble counts at Selected Cross Sections

	5+00	9+00	11+00	13+50	16+00	19+50	23+00	27+00
D_{50}	49	31	28	40	40	36	49	54
D_{84}	83	61	55	70	80	75	86	96

Bulk Samples

Each bulk sample taken from the channel included two batches excavated by shovel into 5-gallon buckets. The first batch consisted of the bed material in the top 0.5 ft, and the second consisted of the substrate below the first batch to a depth of approximately 1.5 ft. Analyzing each batch separately revealed the characteristics of each layer. The results of the material analyses were combined to generate the gradation curves listed in Appendix C. Table 2 summarizes the D_{50} and D_{84} sizes for both layers and the average, which gives a better representation of the material before any vertical stratification may have occurred.

Table 2 Surface and Substrate Particle Sizes of Bulk Samples

(*Sizes in mm*)

	Surface		Substrate		Average	
Cross Section	D_{50}	D_{84}	D_{50}	D_{84}	D_{50}	D_{84}
5+00	22	54	22	59	22	57
11+00	34	80	24	80	29	80
16+00	33	67	35	110	34	89
23+00	35	114	37	86	36	100
27+00	53	94	46	118	50	106

Spring of 2000 Monitoring

Subsequent monitoring employs the same techniques used in baseline monitoring so that results can be compared to yield a quantitative description of how the channel has changed. Changes that are being evaluated include migration of the channel, gains or losses of material, and movement of material.

Cross Sectional Survey

Cross sections were surveyed in October 2000. Some of the surveyed cross sections did not follow the established monitoring section lines precisely and were either eliminated from comparison or were conditionally allowed.

Tracer Gravel

A straight section of channel between stations 23+00 and 27+00 was chosen for placement of the tracer gravel. The channel at these stations is relatively straight with a consistent geometry to provide fairly uniform flows over the cross section and consistent movement of material. Station 23+00 is at the upstream end of a riffle section approximately 100 ft downstream of a bend, and station 27+00 is roughly 50 ft above the tail of the riffle and upstream of another bend at the end of the reach. Tracer gravel placed at stations 23+00 and 27+00 corresponded to the D_{50} and D_{84} sizes based on the November 1999 pebble counts (Table 1). Movement of the D_{84} particle implies general bed mobility. D_{50} particles are used in sediment transport calculations. In December 1999, 50 rocks matching the D_{50} size and 50 rocks matching the D_{84} size were marked and placed at each section. The rocks were placed by setting them on the cross section and inserting them by force into the surface layer of the bed to simulate natural deposition. Flows exceeded bankfull for 36 days, peaking at 3,408 cfs on February 23, 2000. These flows caused not only movement of the tracer gravel at both locations, but also some bank erosion at station 23+00 and deposition at a point bar below the monitored reach (Figure 5). The average flow during this period was 2,499 cfs.

Figure 5 Developing Point Bar at Station 29+00

The quantity, approximate distance traveled and lateral location of the recovered tracer gravel was recorded. Twenty-nine rocks were recovered at station 23+00, accounting for 16% of the D_{50} and 42% of the D_{84} gravel placed. Of the recovered gravel, 93% was on the right side of the channel where slower, shallower water contributes to lower shear forces because it is in a transition from pool to riffle (Figure 6). Lower shear force would account for lower transport rates for these rocks keeping them in the recovery area. The lack of movement of two rocks recovered in the left center location was most likely caused by placement behind a boulder or deeper placement into the bed.

Figure 6 Cross Section 23+00 Tracer Gravel Movement

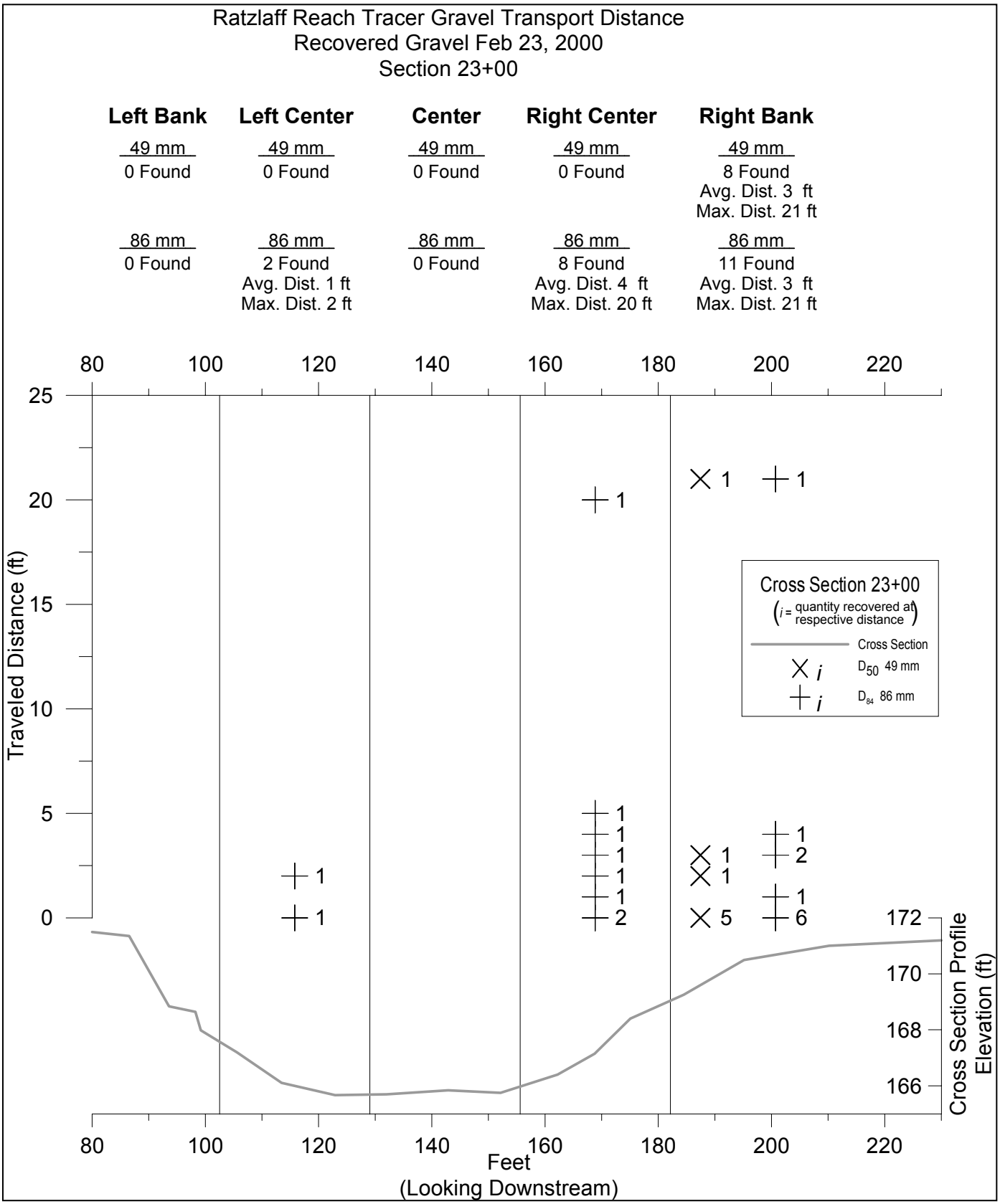
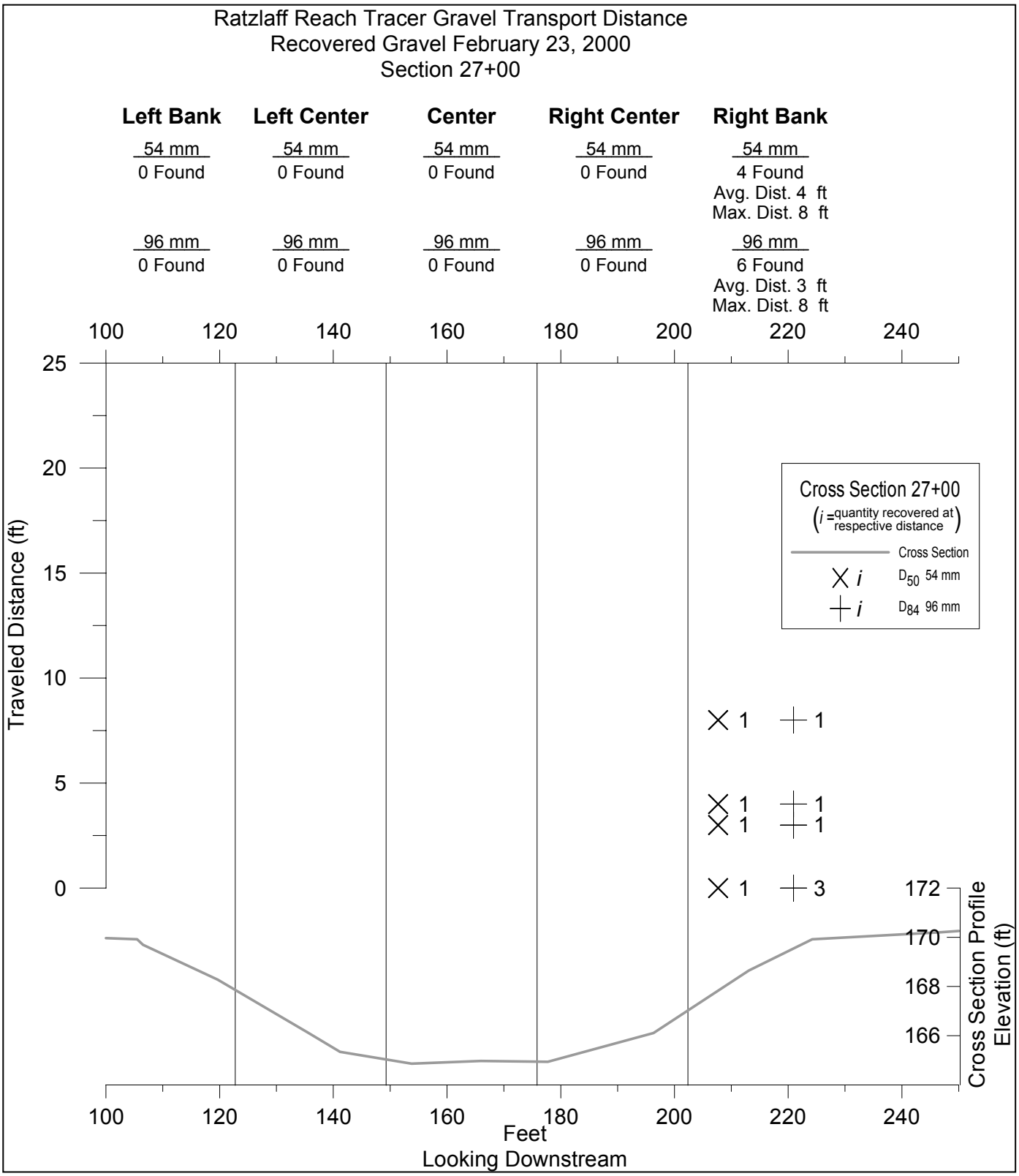


Figure 7 Cross Section 27+00 Tracer Gravel Movement



Cross section 27+00 was similarly lacking in tracer gravel with only 10 rocks located. The recovered rocks represented 8% of the D_{50} and 12% of the D_{84} placed. All of the recovered gravel was located at the right bank, and it had traveled less than 8 feet downstream (Figure 7). As in section 23+00, the right bank experienced lower shears and lower transport rates based on the recovery rate of the rocks.

Bank erosion near the left bank of station 23+00, formation of a point bar below station 29+00, and the disappearance of tracer gravel suggest that most of the particles were transported outside of the recovery area in both cases. Additionally, shears calculated in the hydraulic model for both stations suggest greater transport rates through the main channel, which explains the removal of the tracer gravel from the recovery zone (Table 3).

Table 3 Tracer Gravel Shears Calculated in the Hydraulic Model

HEC-RAS Plan: As-Built River: Merced R. Reach: Ratzlaff Reach

3,408 cfs

Station	Model Sta	Min Ch El (ft)	W.S. Elev (ft)	Hydr Depth C (ft)	Shear LOB (N/m^2)	Shear Chan (N/m^2)	Shear ROB (N/m^2)
22+00	170	165.16	172.49	5.26	3.17	17.32	3.71
23+00	160	165.30	172.21	4.89	4.86	25.54	5.40
25+00	140	165.01	171.91	4.74	4.42	23.35	4.96
27+00	120	164.78	171.56	4.91	5.78	24.43	5.82
29+00	100	164.65	171.34	5.36	8.96	23.68	7.62

Water Surface Elevations

Water surfaces were marked at several locations during river flows of 1,686 cfs and 2,594 cfs on February 25 and April 26, 2000 that were approximately at or exceeding the bankfull flow. The water surface marks were surveyed for elevations and locations, and the corresponding river flows were estimated from Snelling stage data. These flows and elevations were used to check and calibrate a hydraulic model of the project reach (Appendix E).

Spring of 2001 Monitoring

Pebble Counts

Pebble counts were performed again in May 2001. Comparison of the pebble count gradation curves of the November 1999 baseline to the May 2001 samples (Appendix D) indicates some coarsening of the bed at some sections. A summary of the D_{50} and D_{84} sizes (Table 4) indicates the same shifts in coarseness when compared with the baseline sizes (Table 1). At stations 5+00, 9+00, and 11+00, the gradation curves indicate increased coarsening of the bed. At stations 13+50 and 16+00, there is no appreciable change, indicating the material is moving through without removing additional material. Station 19+50 is showing a decrease in coarseness, which may be due to the greater radius of curvature and length of that pool section than that of the other

pools being monitored. Stations 23+00 and 27+00 have become coarser apparently because midrange particles are being transported out of these areas without being replaced.

Table 4 Particle Sizes from May 2001 Pebble Counts at Selected Cross Sections

	5+00	9+00	11+00	13+50	16+00	19+50	23+00	27+00
D_{50}	53	36	42	38	43	34	56	61
D_{84}	83	62	93	71	80	60	89	135

Data Analysis

Hydraulics

Proper evaluation of geomorphic processes is dependent on adequate data for water surface profiles and slopes, shear forces, Manning's friction factor "n", and water depth. A HEC-RAS model was used to determine a water surface profile based on the Snelling stage data. Manning's "n" was evaluated through a comparison of calculated water surface profiles and the surveyed water surface elevations and was determined to be 0.03 in the active channel and 0.06 to 0.07 on the floodplain. The modeled water surface profile for 1,686 cfs indicates a bankfull flow with the water surface at the threshold of the floodplain as the design intended. This threshold is a reasonable match to the water surface elevation survey for the 1686 cfs flow, which indicated this flow was beginning to spill onto the floodplain. Additionally, the modeled elevations matched within 0.32 feet of the surveyed water elevations at flows of 1,686 cfs and 2,594 cfs (Appendix E).

Sediment Transport

During the design process (DWR 2000), the critical shear for sediment movement was determined from Shields equation, $\tau_{ci} = 1.65\tau_{ci}^{*}\gamma D_i$. τ_c is the shear force at which movement begins for the D_i sized particle; τ_c^{*} is the dimensionless critical shear corresponding to the force required for a particle to begin moving; and γ is the specific weight of water. Actual values for τ_c^{*} can be greater than 0.02, with 0.02 being the lower limit for movement to occur. Finer particles are usually assigned larger values because they are sheltered from some of the force by the surrounding coarser particles. In contrast, the coarse particles are assigned smaller τ_c^{*} values because they protrude into the channel where shears are greater.

The designers considered the way the gravel would be arranged in the surface layer when placed artificially during construction and assumed smaller particles would fill in between the larger particles up to the top of the largest particles. Filling the surface layer this way would provide equal projection of the D_{50} and D_{84} particles in the channel so the dimensionless critical shear would not follow the convention. A value of 0.02 was used for τ_c^{*} for both the D_{50} and D_{84} to estimate critical shear at bankfull flow. Using 0.02 for τ_c^{*}, and D_{50} and D_{84} values of 61 mm and 170 mm determined from sieve analyses, the Shields equation resulted in critical shears of 19.73

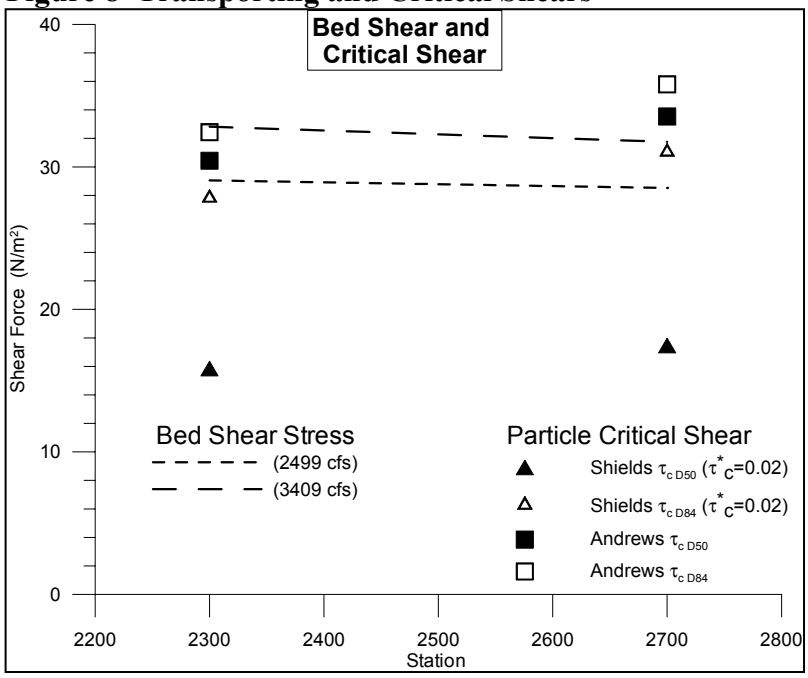
N/m^2 and 54.99 N/m^2. This situation would hold true until a large flow event rearranged the gravel, after which the more conventional shear calculations would apply.

Table 5 Critical Shears Calculated Using Shields Equation

Shields $\tau_c^* = 0.02$				
Station	**D50**	**τ_c**	**D84**	**τ_c**
Design	61	19.73	170	54.99
23+00	49	15.85	86	27.82
27+00	54	17.47	96	31.05

A comparison of the D_{50} and D_{84} sizes used for design to the baseline pebble count sizes shows that the placed gravel was actually smaller on average than the design gravel size (Table 1). A smaller gravel size will reduce the expected critical shears required to cause movement (Table 5), making comparison of τ_c^* between the design and as-built data more difficult. By using the baseline monitoring data, the shear required to move the existing material can be predicted and used to make comparisons with the tracer gravel experiment results, indicating differences between the assumed and determined values of τ_c^*.

Figure 8 Transporting and Critical Shears



Bed shears were calculated using the peak and average of flows that exceeded bankfull during tracer gravel monitoring in spring 2000 (Appendix F). These are plotted along with the critical shears to move the D_{50} and D_{84} in Figure 8. The particle critical shears were determined using the baseline data for particle sizes and the design assumption that $\tau_c^* = 0.02$. The figure implies that shears were sufficient during this event to move the D_{50} and D_{84} particles, assuming $\tau_c^* = 0.02$.

Dimensionless shear values were back-calculated using the

Table 6 Tracer Gravel Particle Shears

Bed and Dimensionless Shears

	@ 3408 cfs			@ 2499 cfs		
	Bed Shear (N/m^2)	$\tau^*_{D_{50}}$	$\tau^*_{D_{84}}$	Bed Shear (N/m^2)	$\tau^*_{D_{50}}$	$\tau^*_{D_{84}}$
Station 23+00	32.82	0.041	0.024	29.05	0.037	0.021
Station 27+00	31.75	0.036	0.020	28.52	0.033	0.02§

§ Rounded to 0.02 to conform to minimum value for movement to occur

flows that moved tracer gravel (Table 6). These calculations indicate that the D_{50} particle moved with a dimensionless shear of less than the 0.036 value determined from the peak flow and probably moved at a dimensionless shear of less than the 0.033 value calculated from the sustained flow.

Another method to model the critical dimensionless shears is Andrews equation, $\tau_c^* = 0.0384\left(\frac{D_i}{D_{50}}\right)^{-0.887}$ (Andrews 1994). It is dependent on a ratio of the particle size in question to the D_{50} particle, which allows for consideration of the protrusion a specific particle will exhibit.

Andrews equation was used to calculate critical dimensionless shears for the D_{50} and D_{84} of the design average used and the baseline measured at stations 23+00 and 27+00 (Table 7). The critical dimensionless shear for the D_{50} is 0.038, which is higher than the 0.033 for Shields criterion (Table 6). The D_{84} Andrews critical dimensionless shear is less than 0.020 for the design and 0.023 at the cross sections.

Table 7 Dimensionless Shears Calculated Using Andrews Equation

	Design	Station 23+00	Station 27+00
$\tau^*_{D_{50}}$	0.038	0.038	0.038
$\tau^*_{D_{84}}$	0.020	0.023	0.023

Morphology

The October 2000 results were compared with the as-built surveys (Appendix B). The comparison indicates minimal change from stations 2+00 through 23+00 and a loss of approximately 135 cubic yards (216 tons) of material between stations 25+00 and 27+00. The October 2000 survey did not indicate any lateral movement of the channel.

The backwater at stations 13+50 to 17+00 shows no appreciable change in material volumes and appears undisturbed from higher flows. Vegetation has grown up to the waters edge on the upstream end and along the toe of the bluff.

Monitoring surveys of stations 12+00, 17+00, and 29+00 do not exactly correspond to the as-built survey locations. Section 12+00 of the spring monitoring survey veered away from the as-built survey line on the floodplain; however, the portion from the left floodplain to the right bank is acceptable for comparison. Section 17+00 was offset from the as-built survey by approximately 10 feet, traversing the opposite side of a pump through the backwater section. Due to the differences involved in the channel between these locations, section 17+00 was not used for comparison. Section 29+00 was within a few feet of the as-built survey at the left bank, but was skewed approximately 100 ft upstream at the right bank point. This makes comparisons for material transported from station 29+00 difficult and they are not included in the material estimates.

Additionally, vegetation is becoming established on the floodplain making it difficult to locate the cross sections for monitoring activities. Additional survey preparation could help cross section bank location in the future.

Conclusions and Recommendations

Sediment Transport

Because the active shear exceeded the predicted critical shear of 17.47 N/m^2 at both study cross sections (Tables 5 and 6), we cannot conclude that the D_{50} particle would move with a dimensionless shear of 0.020. However, the rate of transport of the tracer gravel implies that a critical dimensionless shear lower than 0.033, as used in the design, may be applicable.

Predicted critical shears for the D_{84} particle were higher than the actual mobilizing shears determined in the tracer gravel study. This discrepancy may be because Shields equation uses a linear relationship with the particle size, but this study's assumed τ_c^* is constant under the assumption that all particles protrude equally.

The results shown in Table 7 imply that particles required less force to move than predicted by the Andrews equation (Figure 8), indicating the protrusion of the particles was greater than predicted in the D_i/D_{50} ratio, which confirms the difference in particle packing between a placed, graded bed and a river armored bed. The D_{50} particle is exposed on the surface rather than nestled in between the D_{84} particles, exposing it to greater shear forces. Once the D_{50} particle starts moving, the D_{84} becomes exposed, and its movement causes bed failure.

General

It is very difficult to conclude whether the design assumptions for mobility of the specified D_{50} and D_{84} are valid or not from this sediment transport study because initial flows far exceeded those which were estimated to be critical for movement. However, further monitoring and analysis can show whether or not the design is working as intended; therefore, pebble counts, sieve analyses, and tracer gravel studies should continue to be used to indicate changes as the gravel is sorted moved through river processes.

The monitoring schedule (Figure 3) lists monitoring activities to be performed after a channel changing event occurs. This section of the Merced River is controlled by flood control and diversion dams. These dams regulate the releases according to agricultural interests and make peak flows rare, unvarying flows common, and relatively low flows the general rule. This can result in long periods between significant changes in channel geometry even though the channel shape was designed to match the existing flow regime. In this respect, the monitoring schedule is adequate. Monitoring activities measure many attributes of the geomorphology of the Ratzlaff Reach and, with sufficient analysis, can give a detailed description of it.

Bank erosion at station 23+00, changes in cross sections 23+00 and 27+00, and the formation of a point bar near cross section 29+00 indicate material movement. Information about the point bar may help in understanding the channel forming ability of the river in this reach. Pebble counts or bulk samples of the bar would indicate the size of the transported material. Cross section surveys would make it possible to estimate the amount of deposition occurring and identify the specific location of the point bar.

The following recommendations may be helpful for continued success of monitoring activities:

- Maintain the existing monitoring schedule and activities;
- Improve survey preparation and execution;

- Include additional pebble counts on the point bar, probably at cross section 30+00;
- Include cross sections 30+00, 31+00 or 32+00 in the cross section survey to monitor material storage in the point bar;

References

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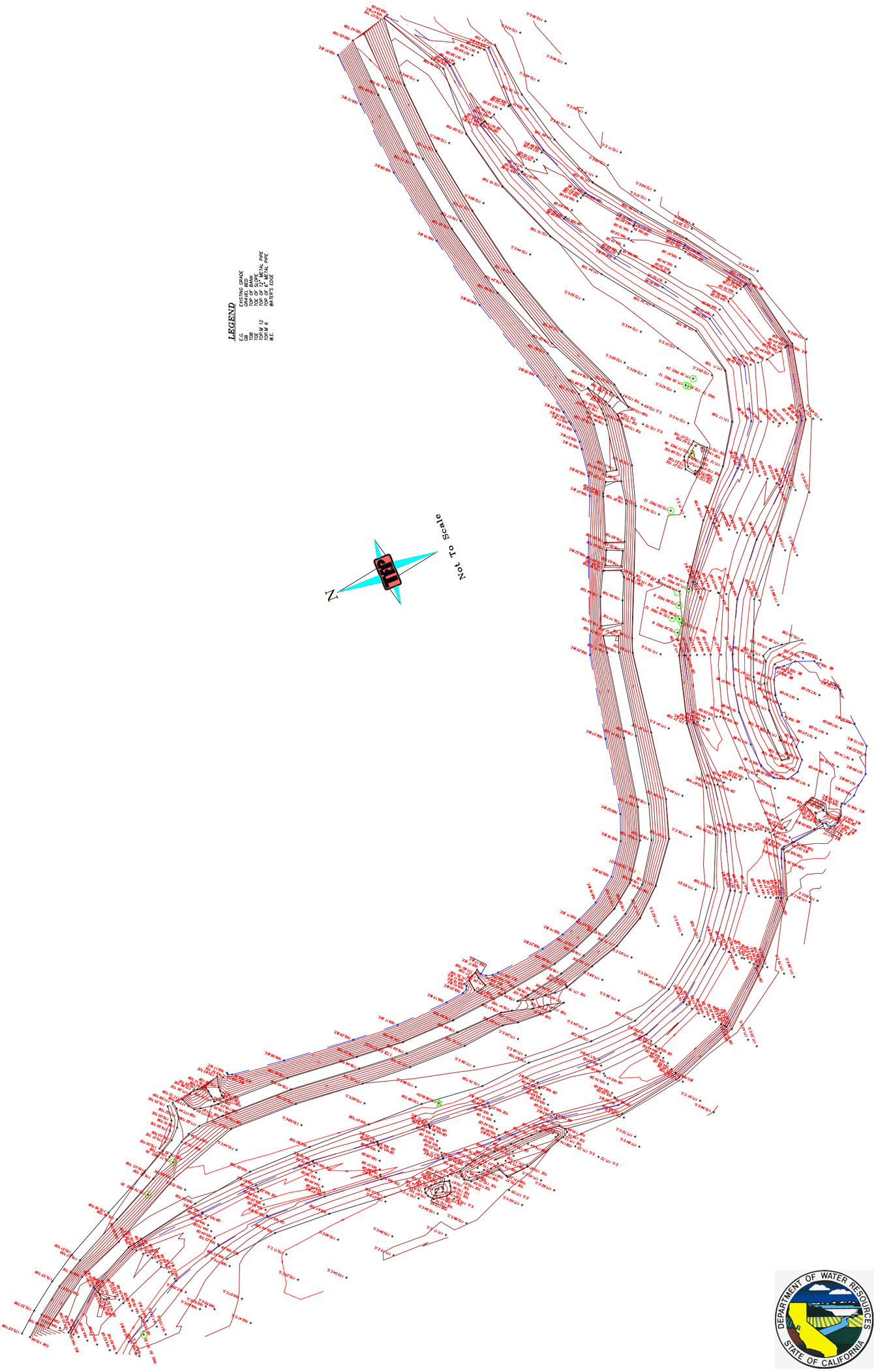
Wolman MG. 1954. A method of sampling coarse river-bed material. Trans Am Geophys Union 35(6):951-6. 4

Appendix A

As-Built Topographic Map and Thalweg Profile



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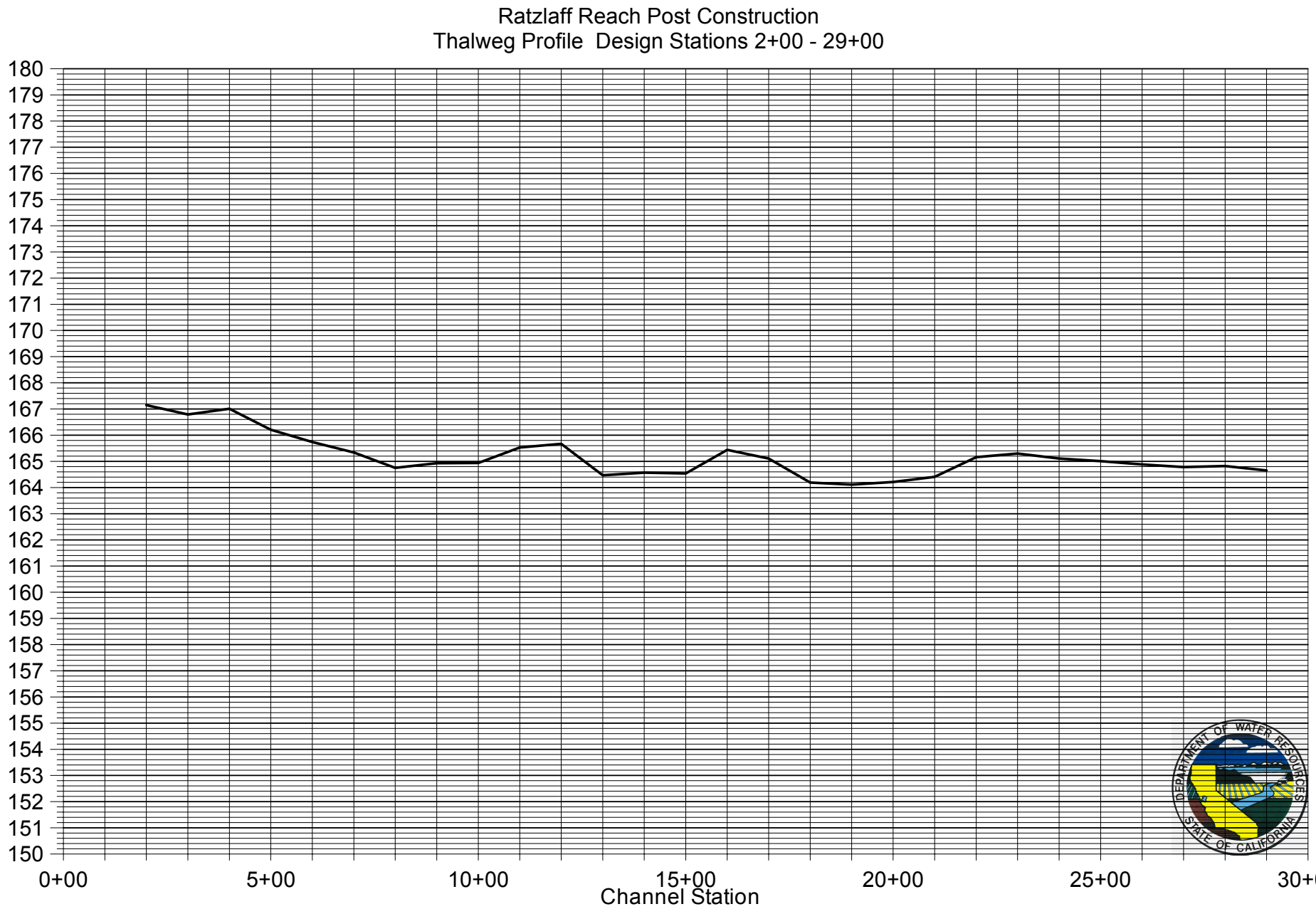
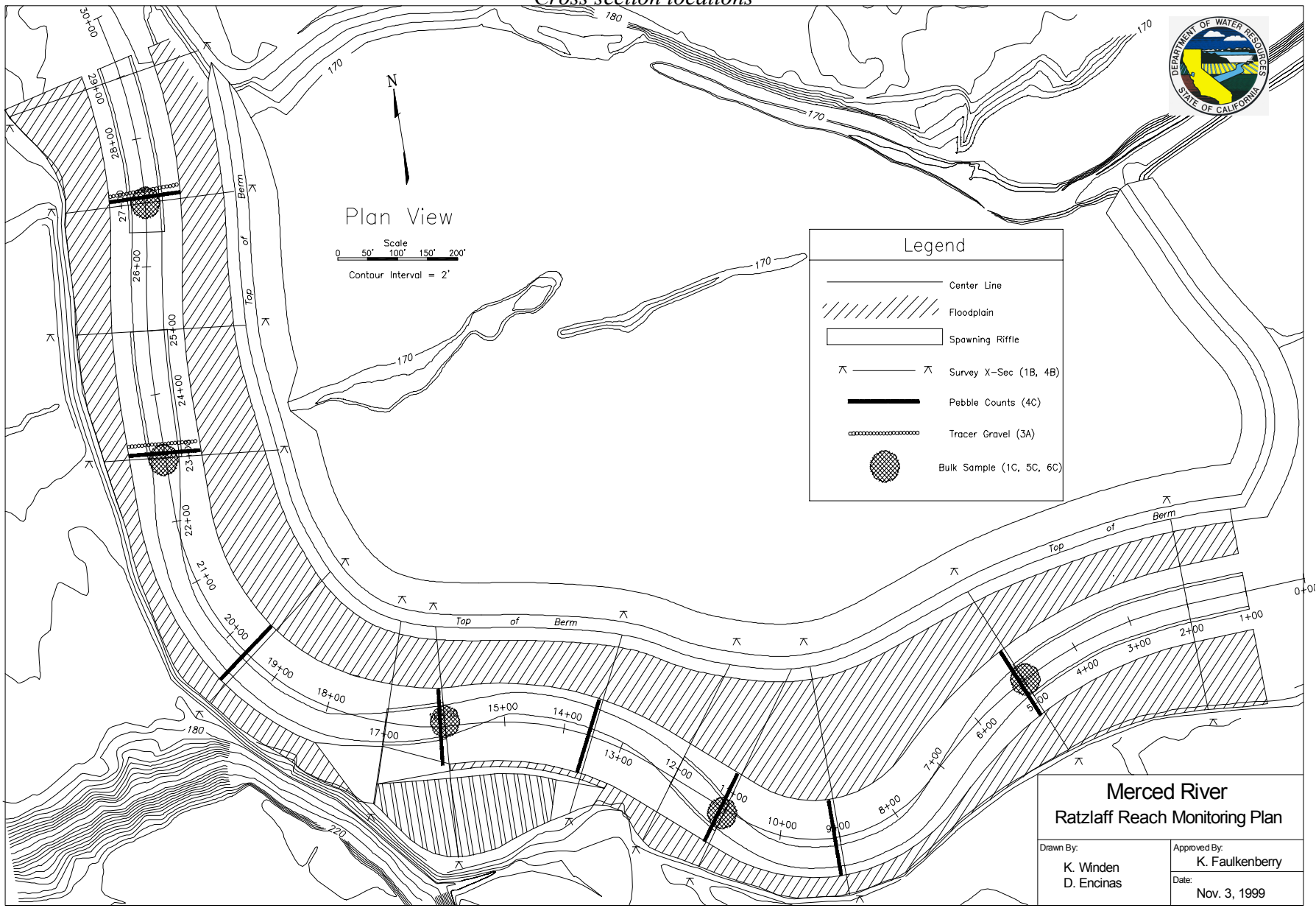


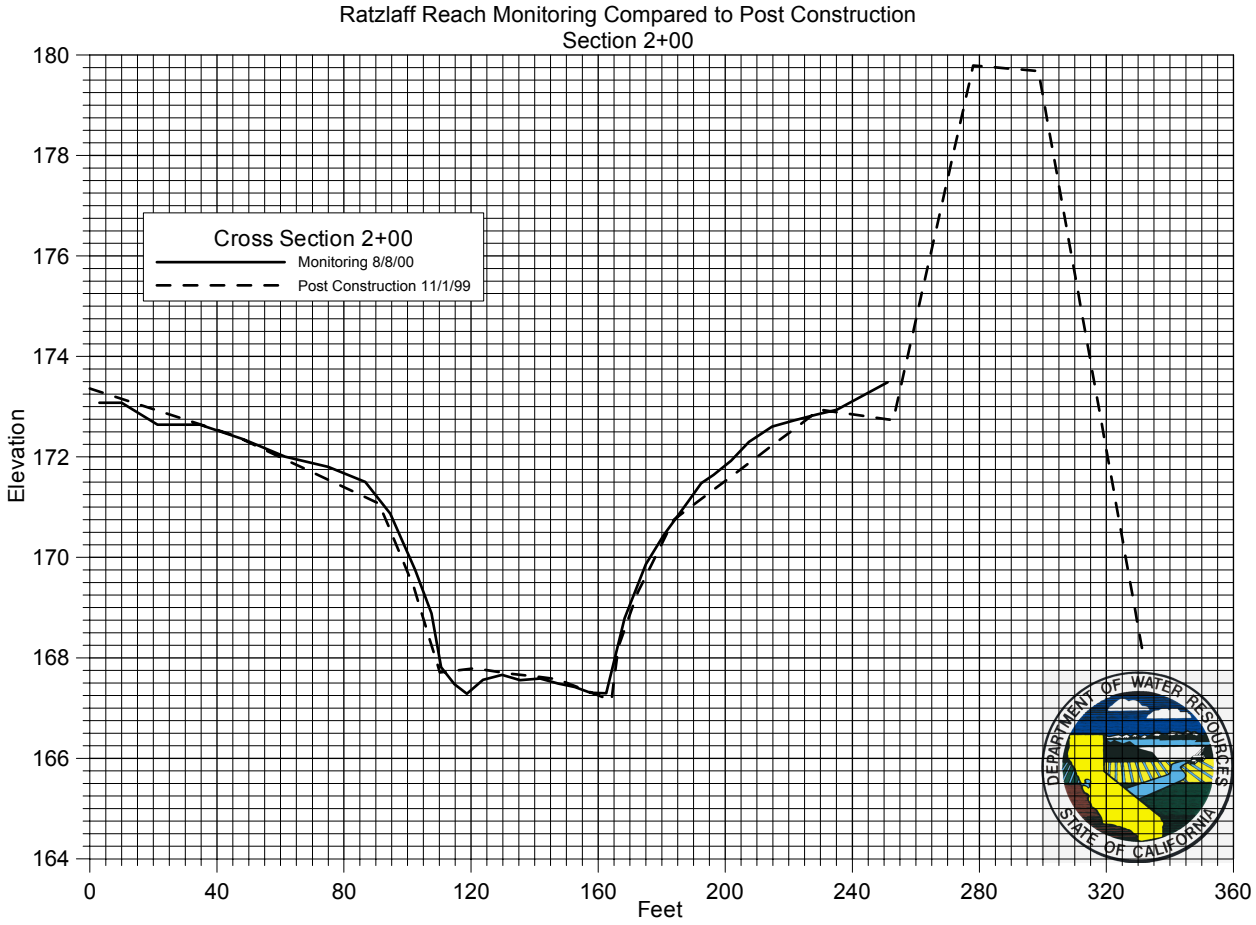
Department of Water Resources
San Joaquin District
River Management Section

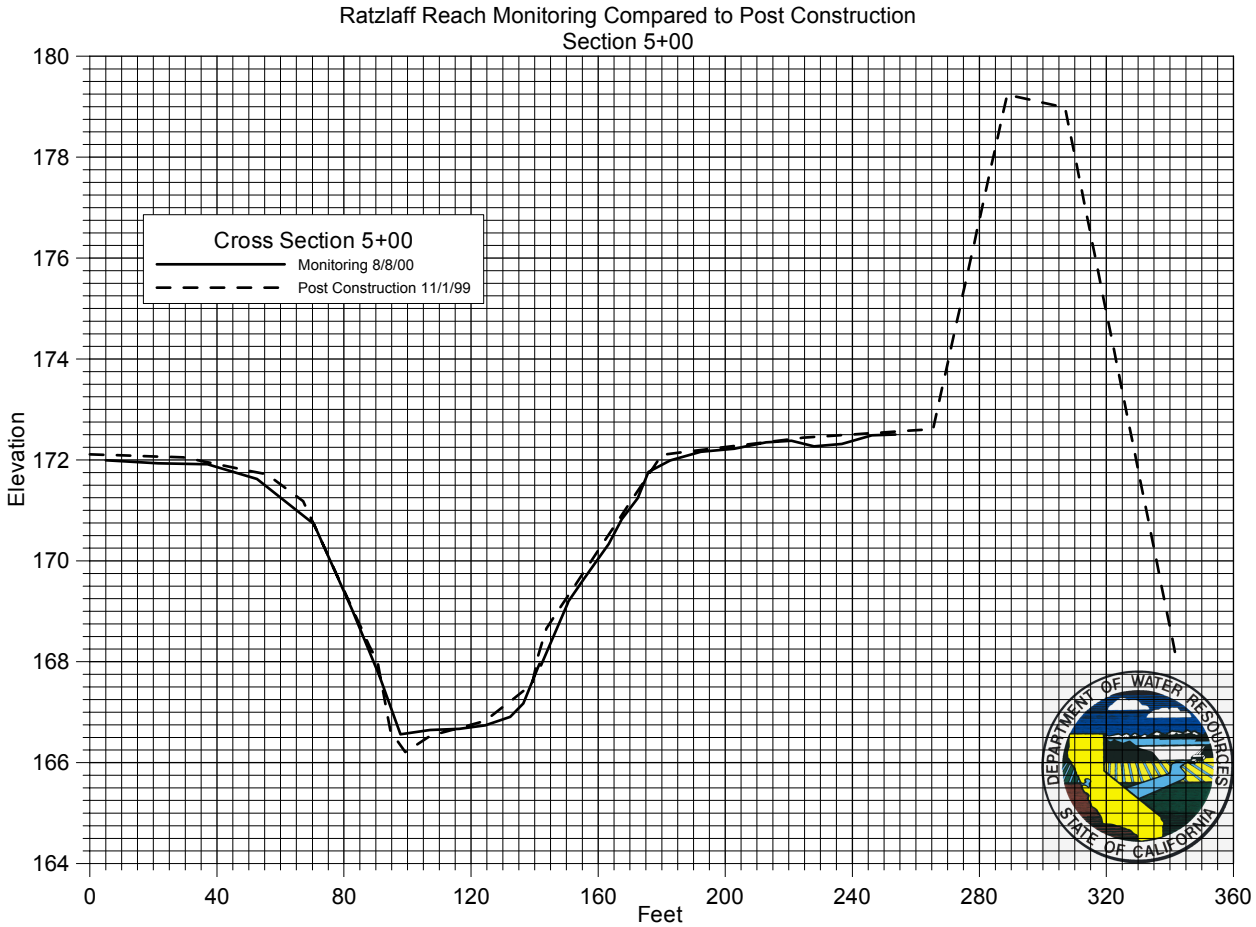
Appendix B

Cross Sections

Cross section locations







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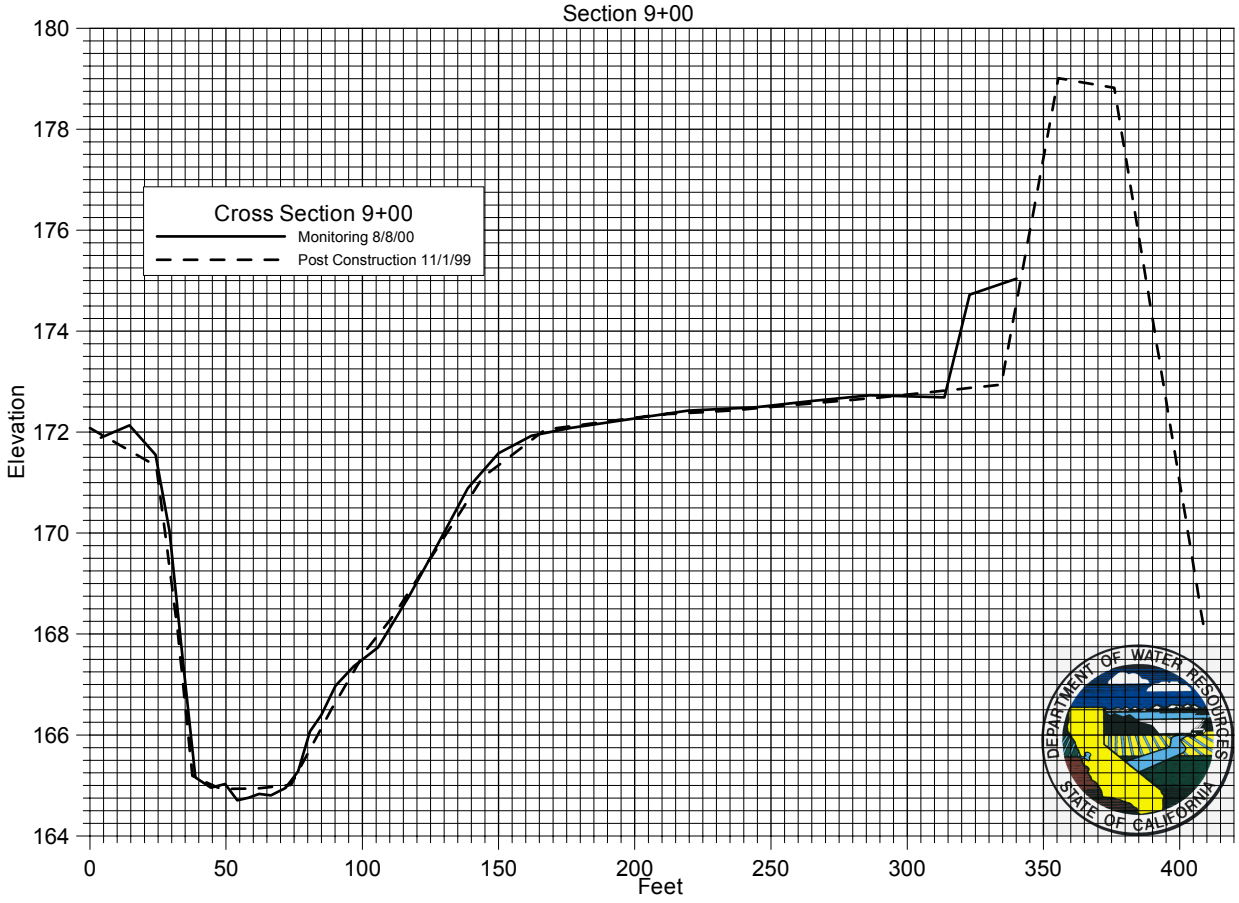
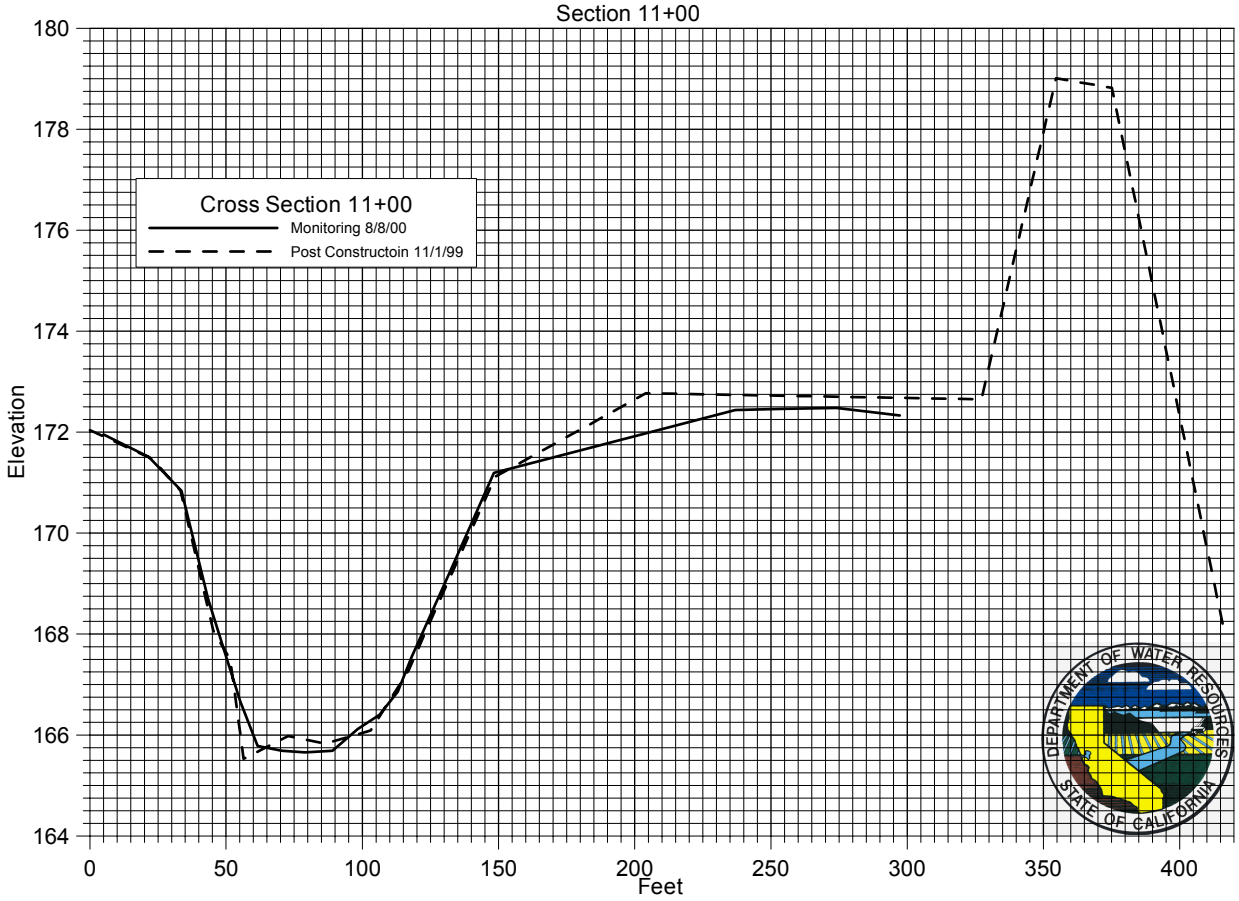
Ratzlaff Reach Monitoring Compared to Post Construction
Section 9+00



Ratzlaff Reach Monitoring Compared to Post Construction
Section 11+00



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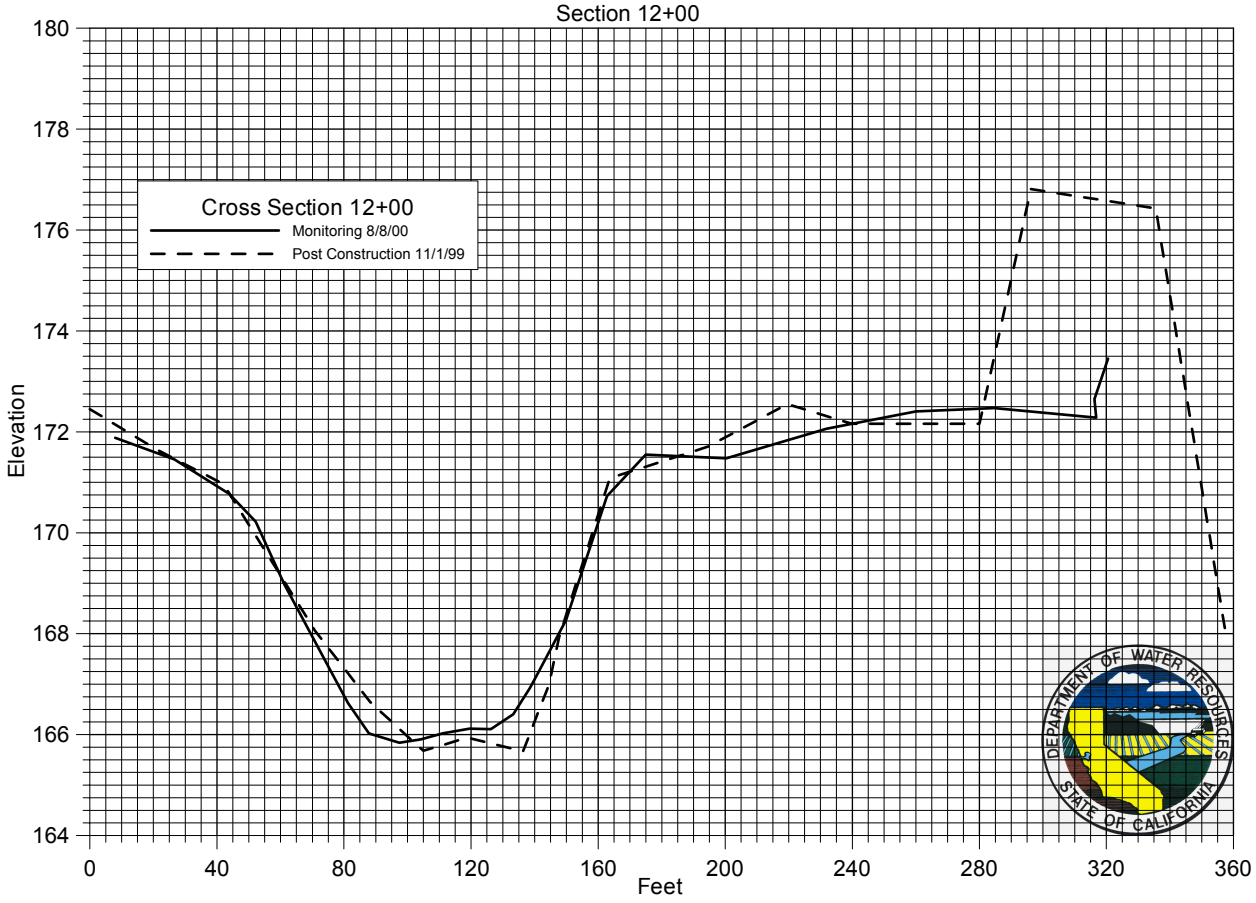
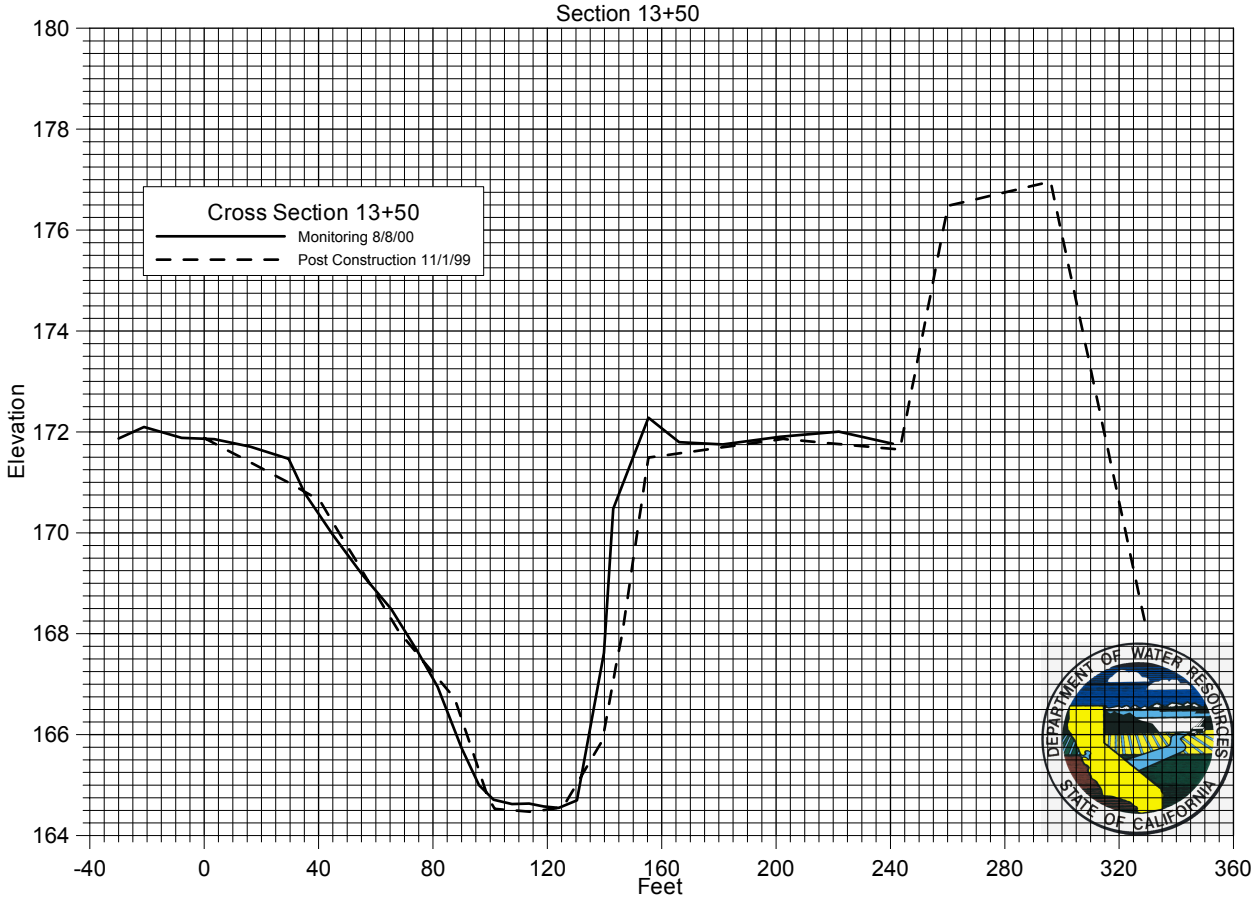
Ratzlaff Reach Monitoring Compared to Post Construction
Section 12+00



Ratzlaff Reach Monitoring Compared to Post Construction
Section 13+50



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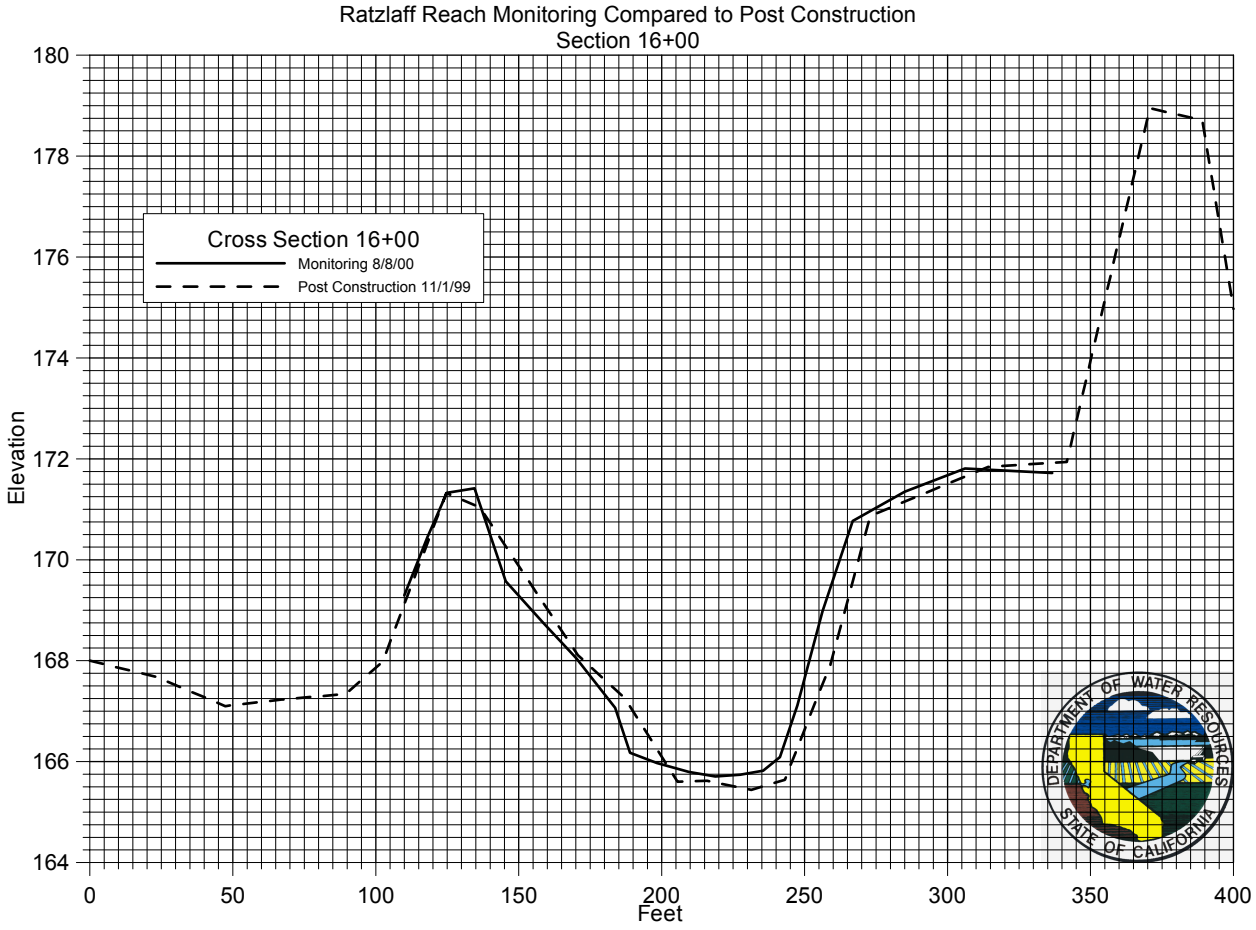
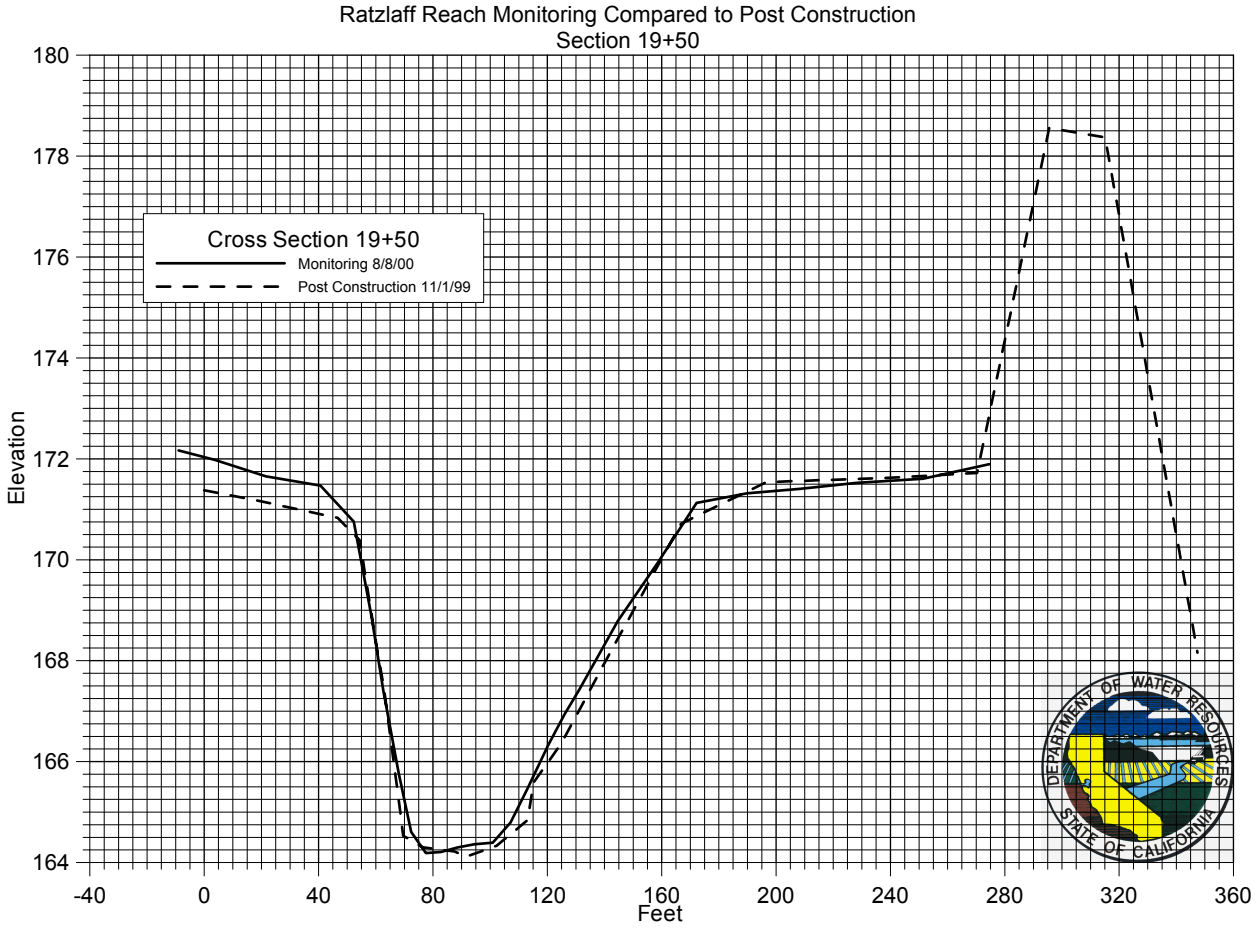
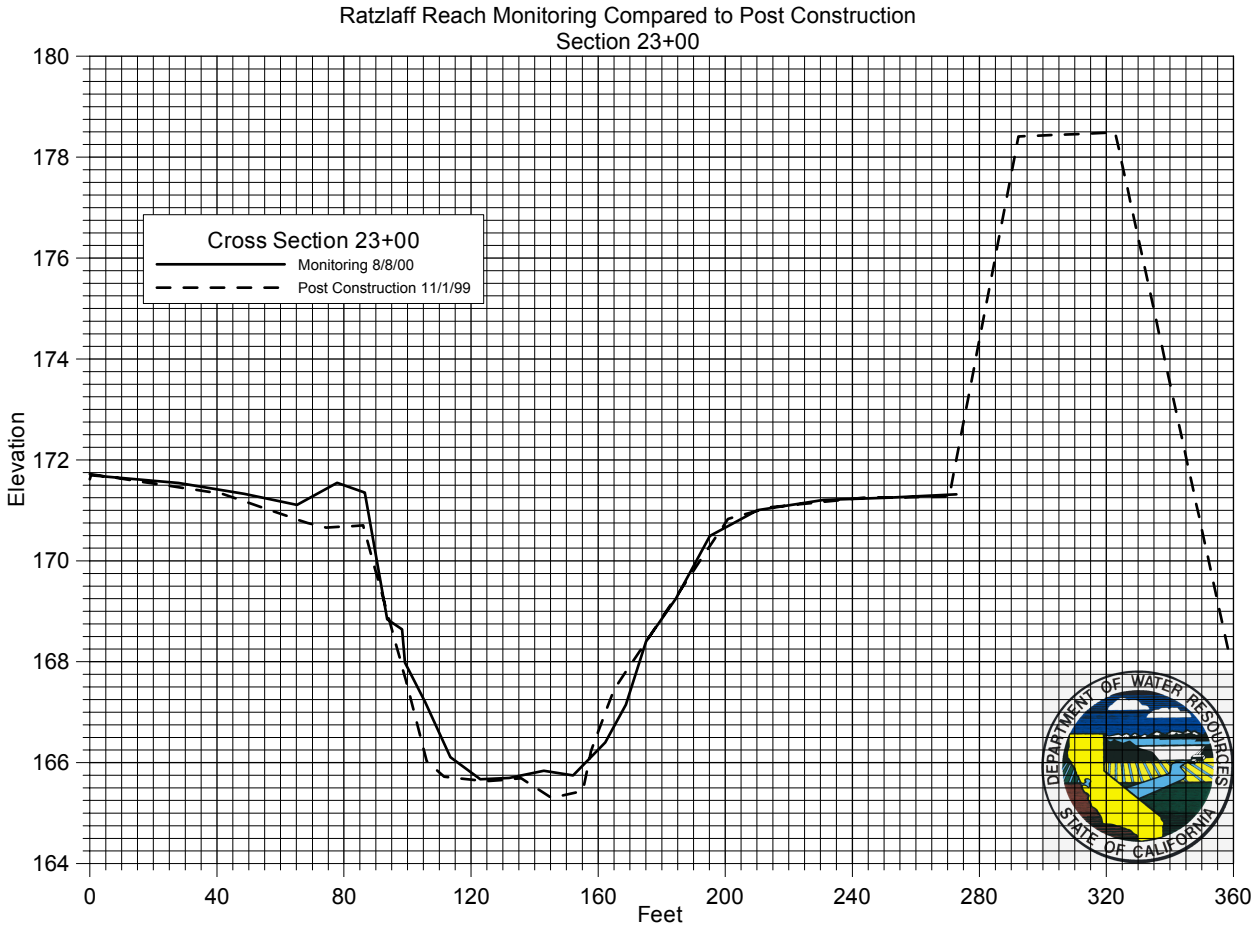

Ratzlaff Reach Monitoring Compared to Post Construction
Section 16+00
Cross Section 16+00
Monitoring 8/8/00
Post Construction 11/1/99
Elevation
Feet
180
178
176
174
172
170
168
166
164
0
50
100
150
200
250
300
350
400





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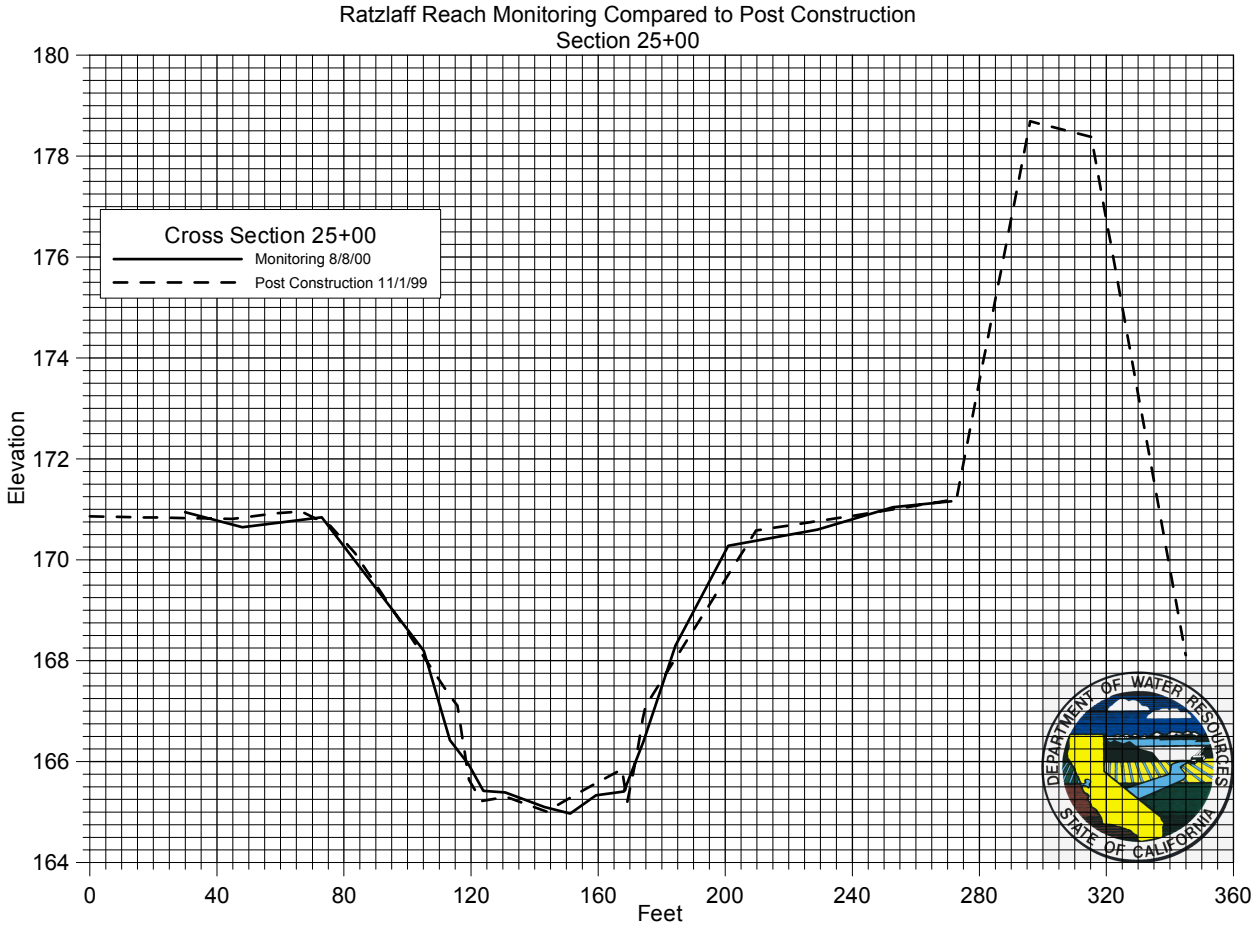

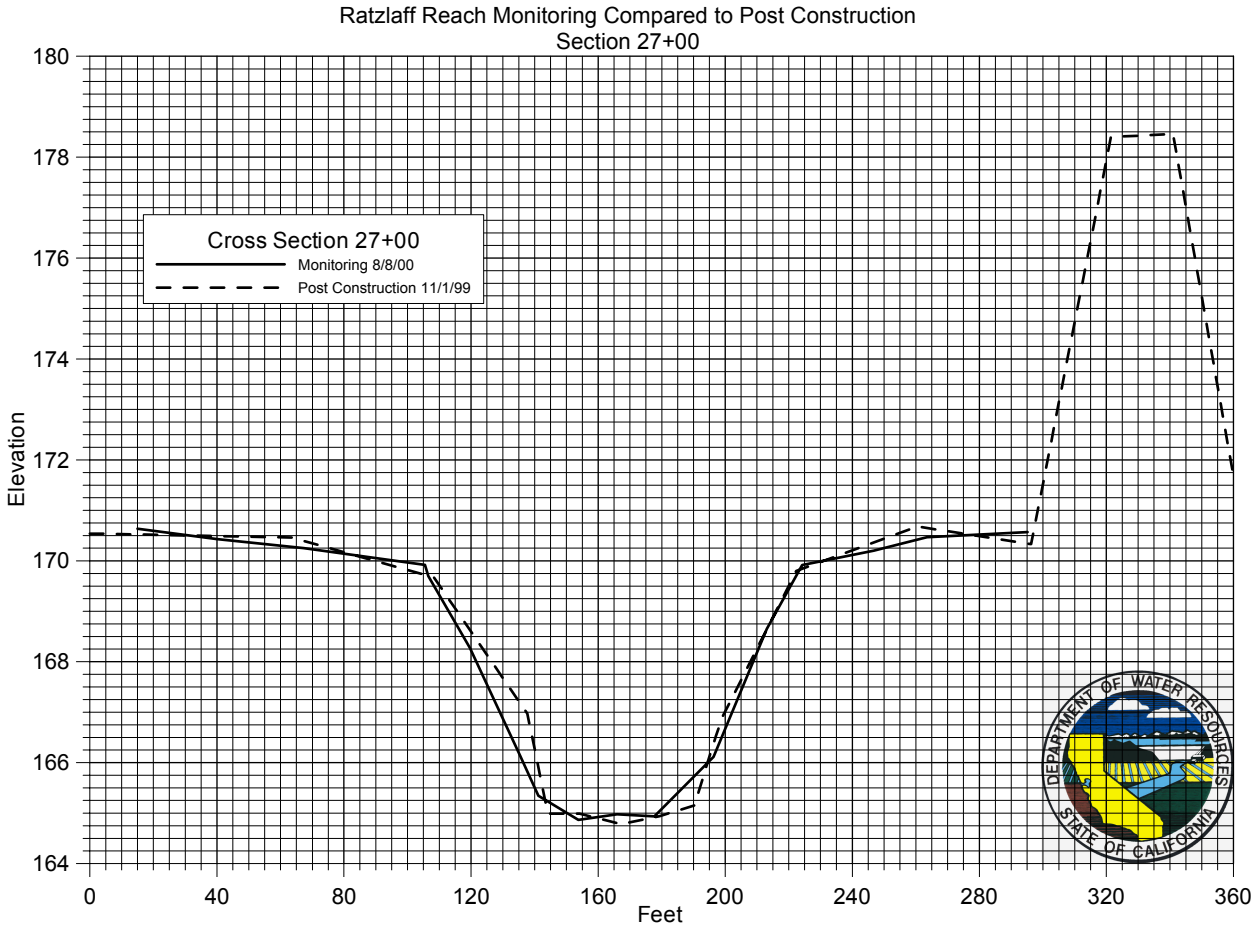

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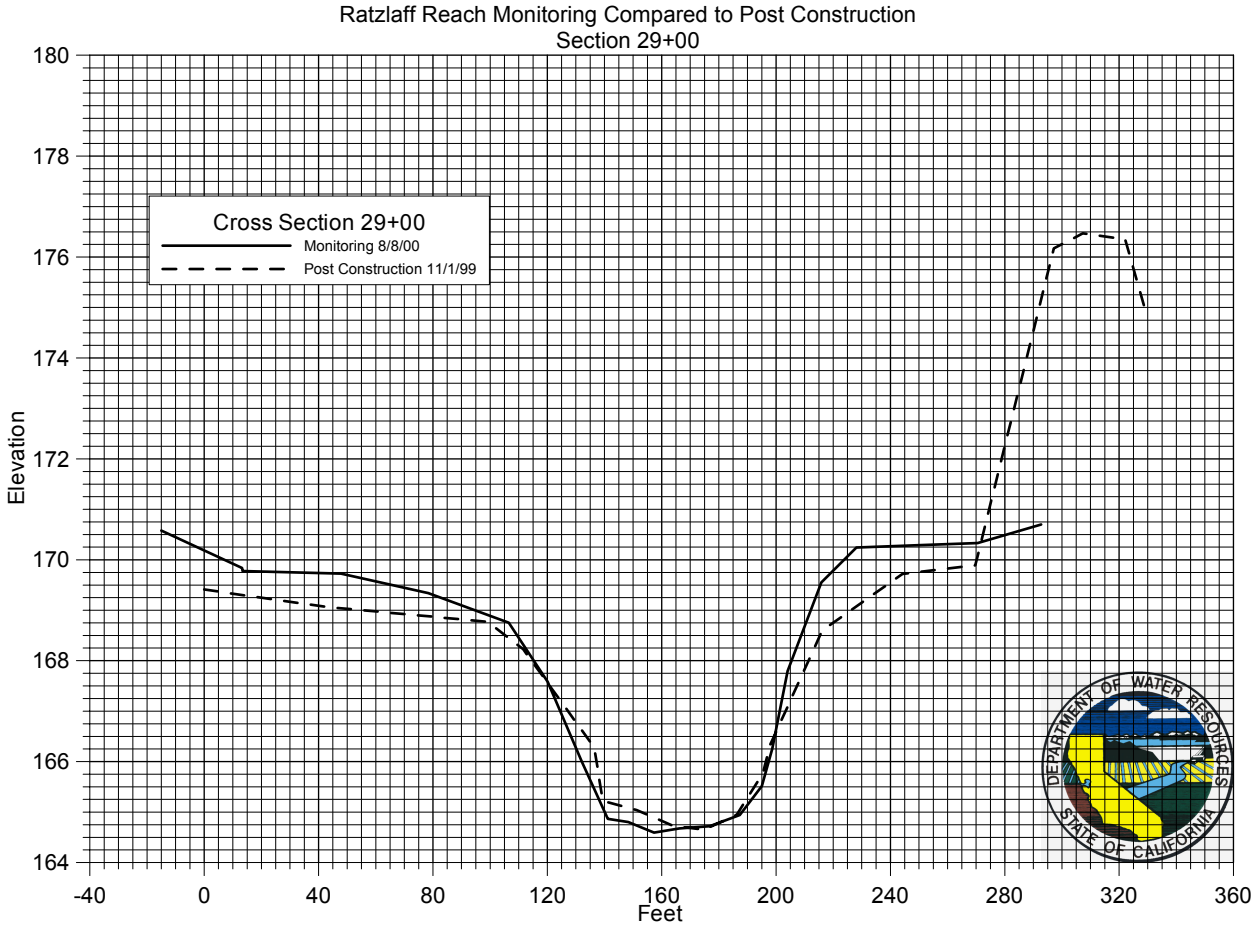

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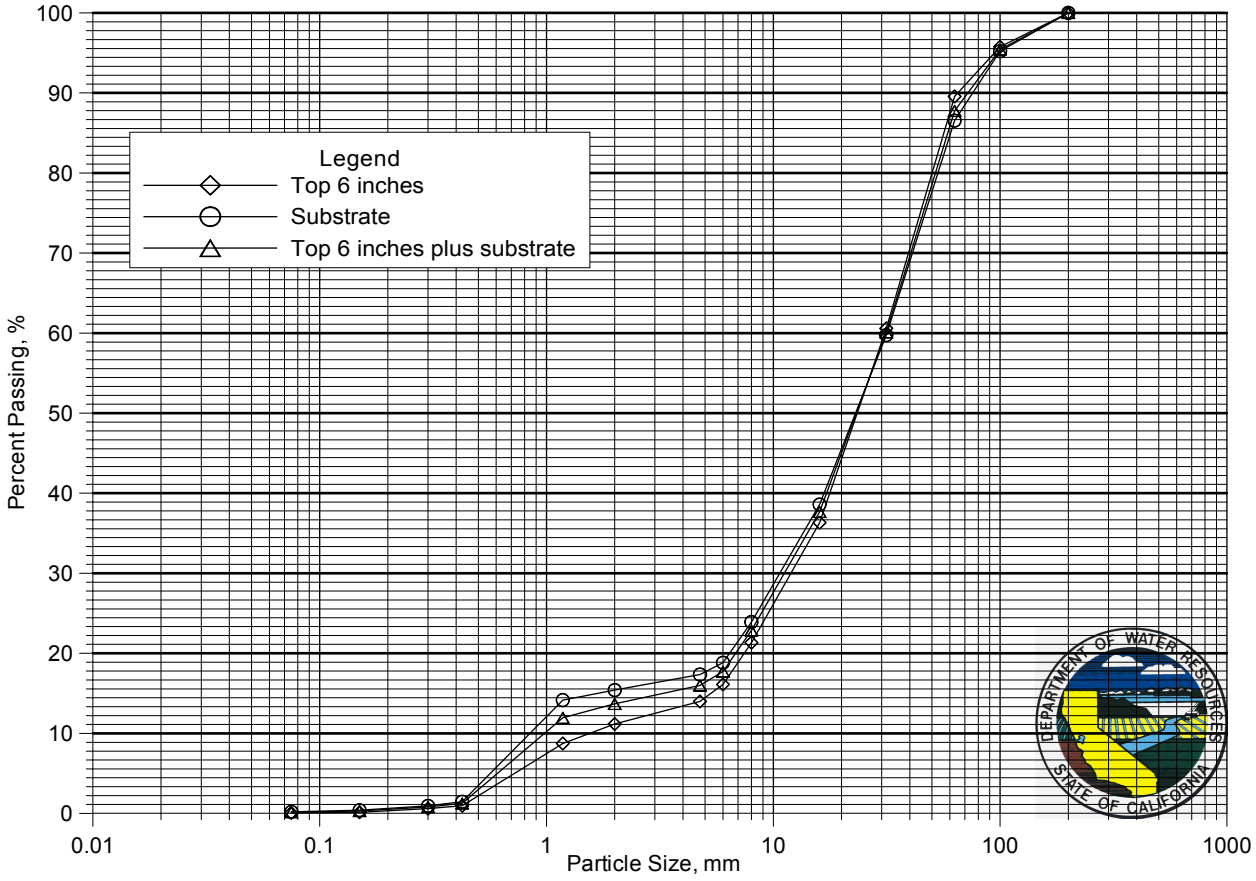
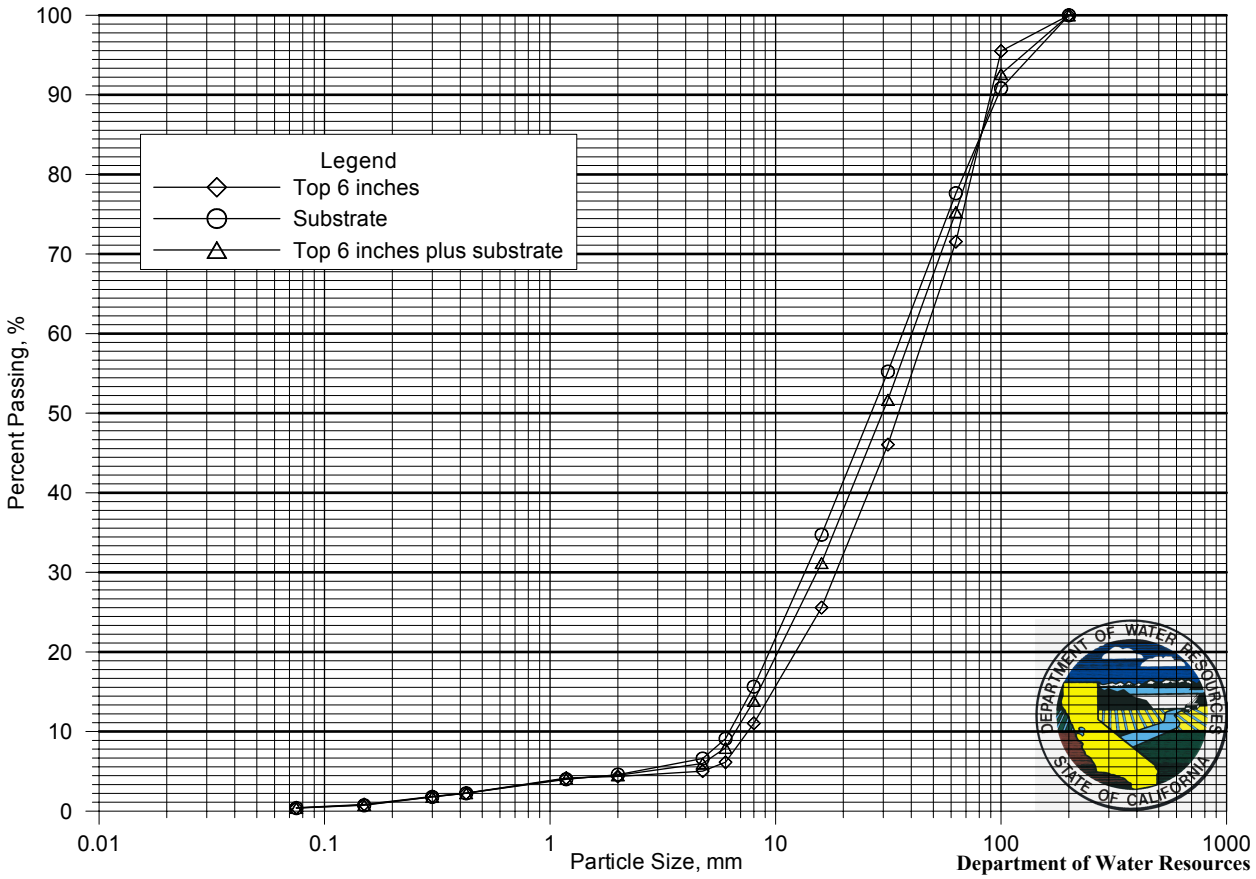
Appendix C

Bulk Analysis

Ratzlaff Reach - Post Construction Particle Size Analysis
Cross-Section 5+00



Ratzlaff Reach - Post Construction Particle Size Analysis
Cross-Section 11+00



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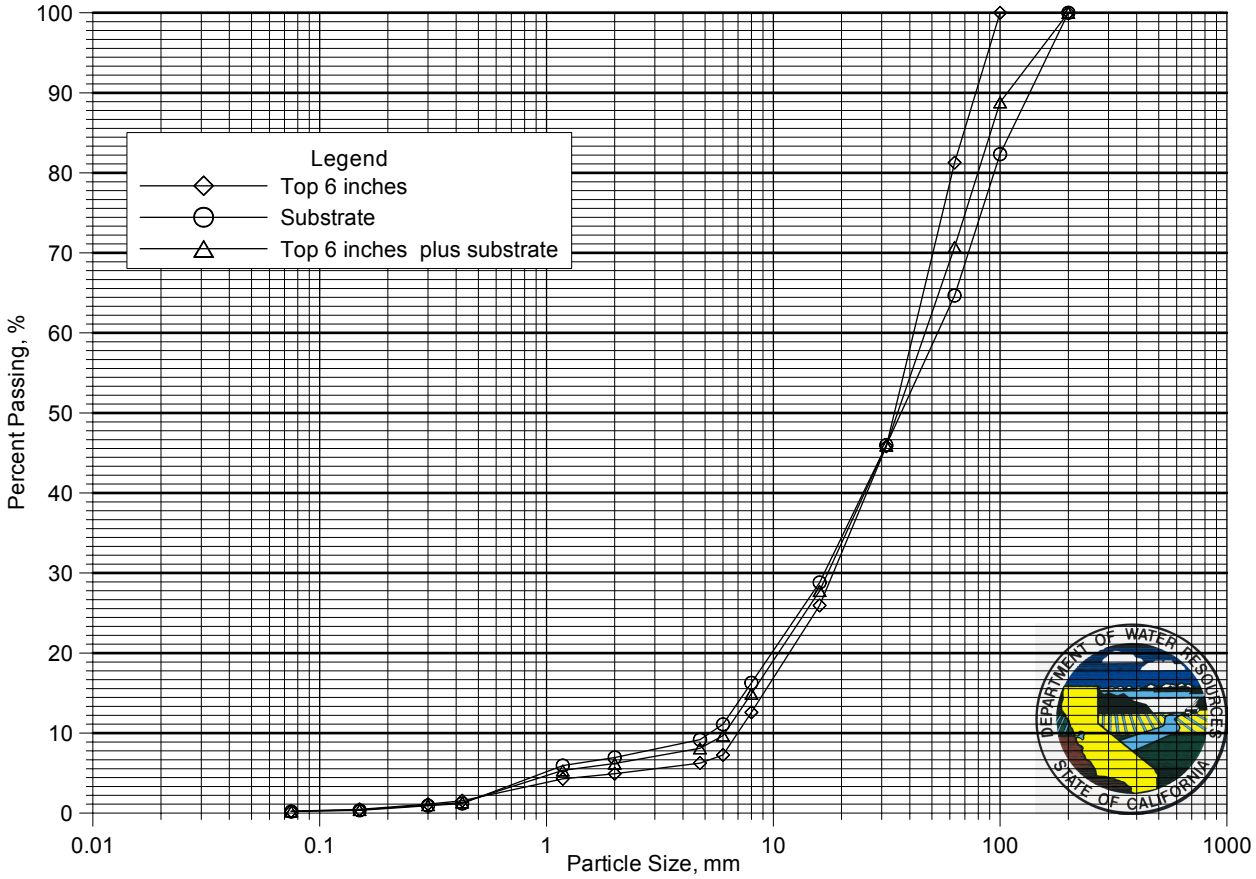
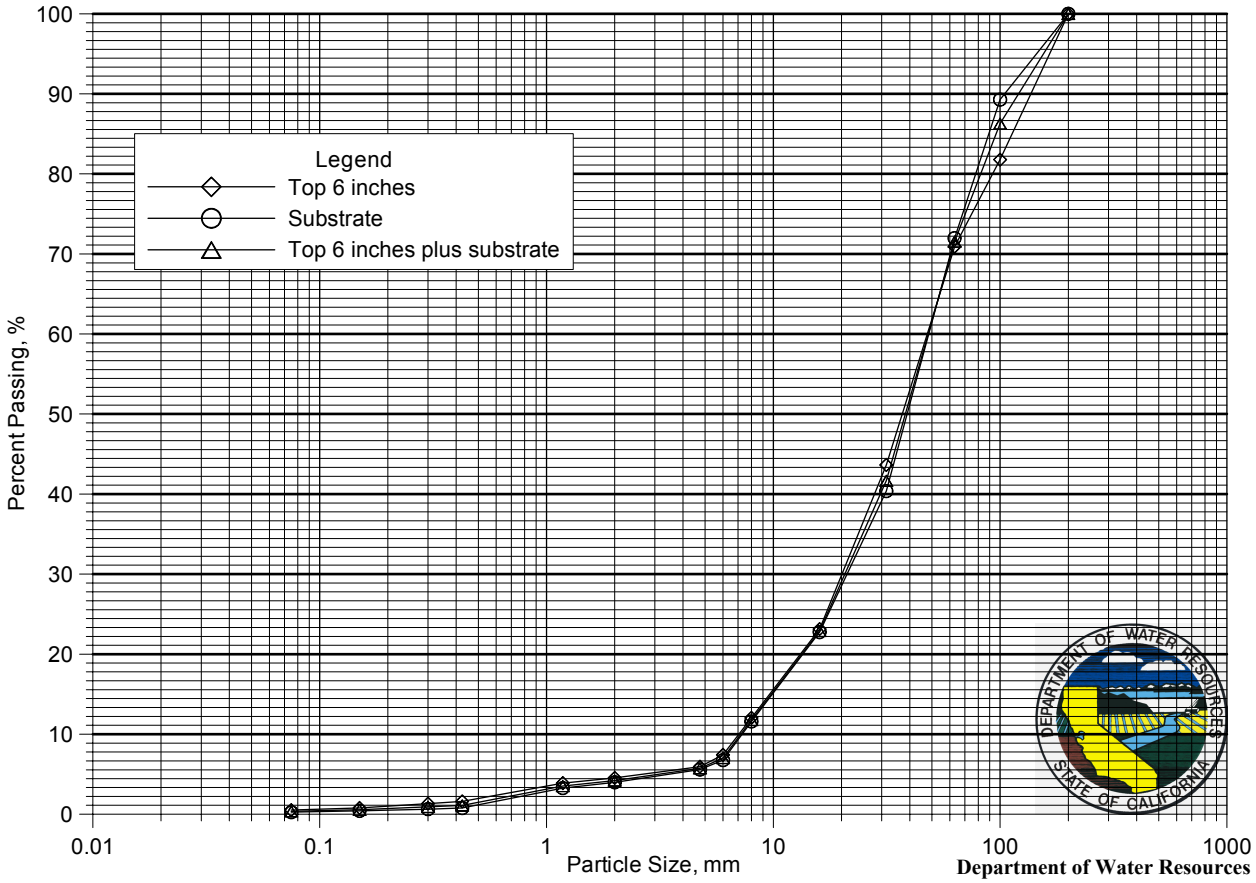
Ratzlaff Reach - Post Construction Particle Size Analysis
Cross-Section 16+00



Ratzlaff Reach - Post Construction Particle Size Analysis
Cross-Section 23+00



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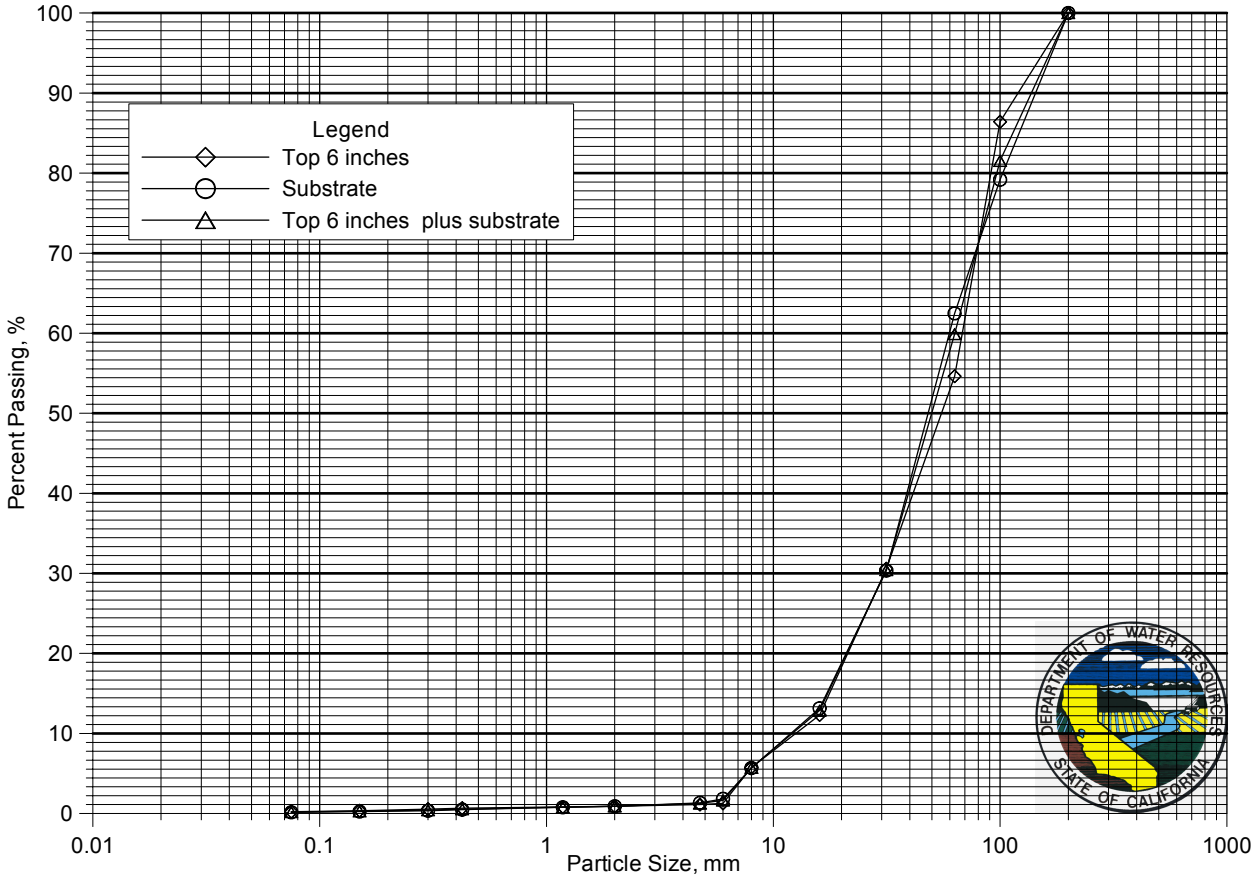
Ratzlaff Reach - Post Construction Particle Size Analysis
Cross-Section 27+00



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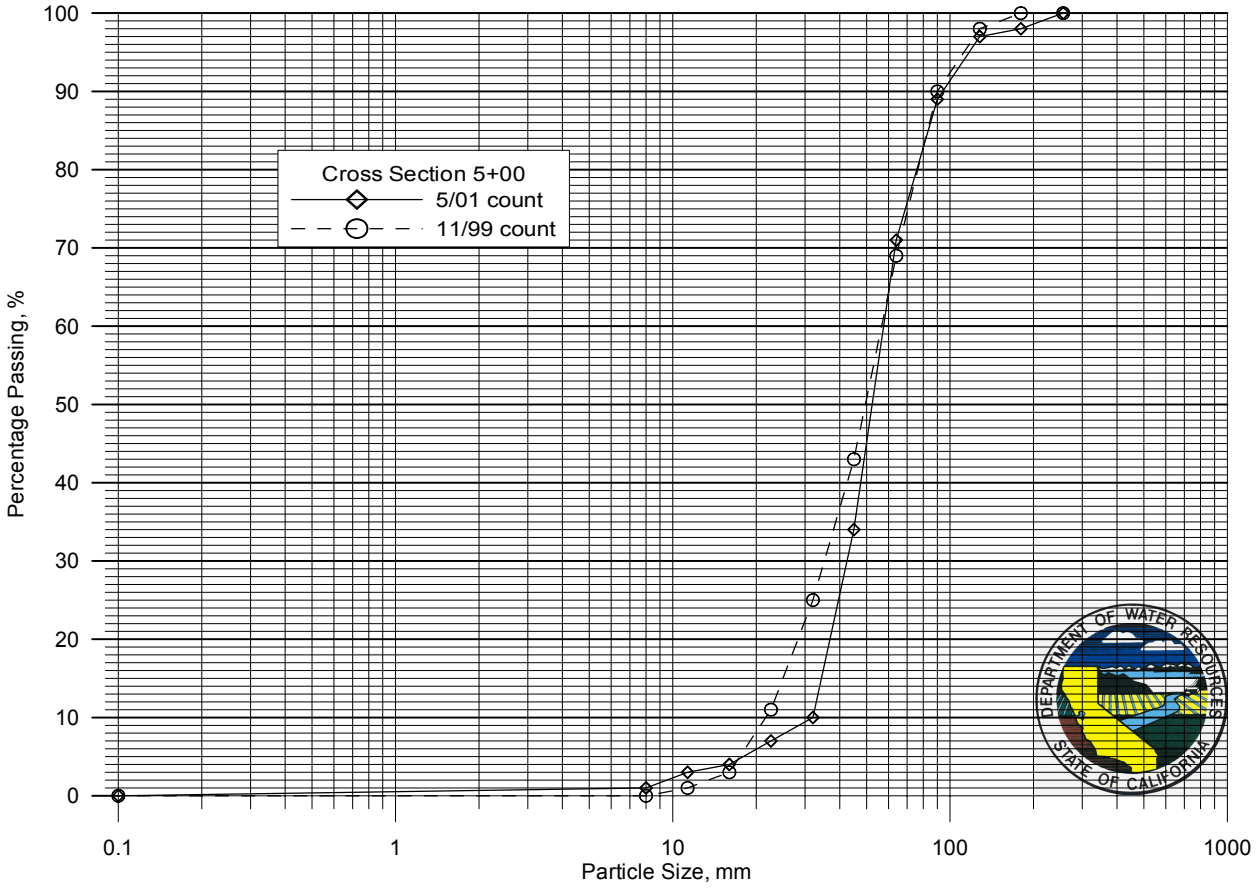
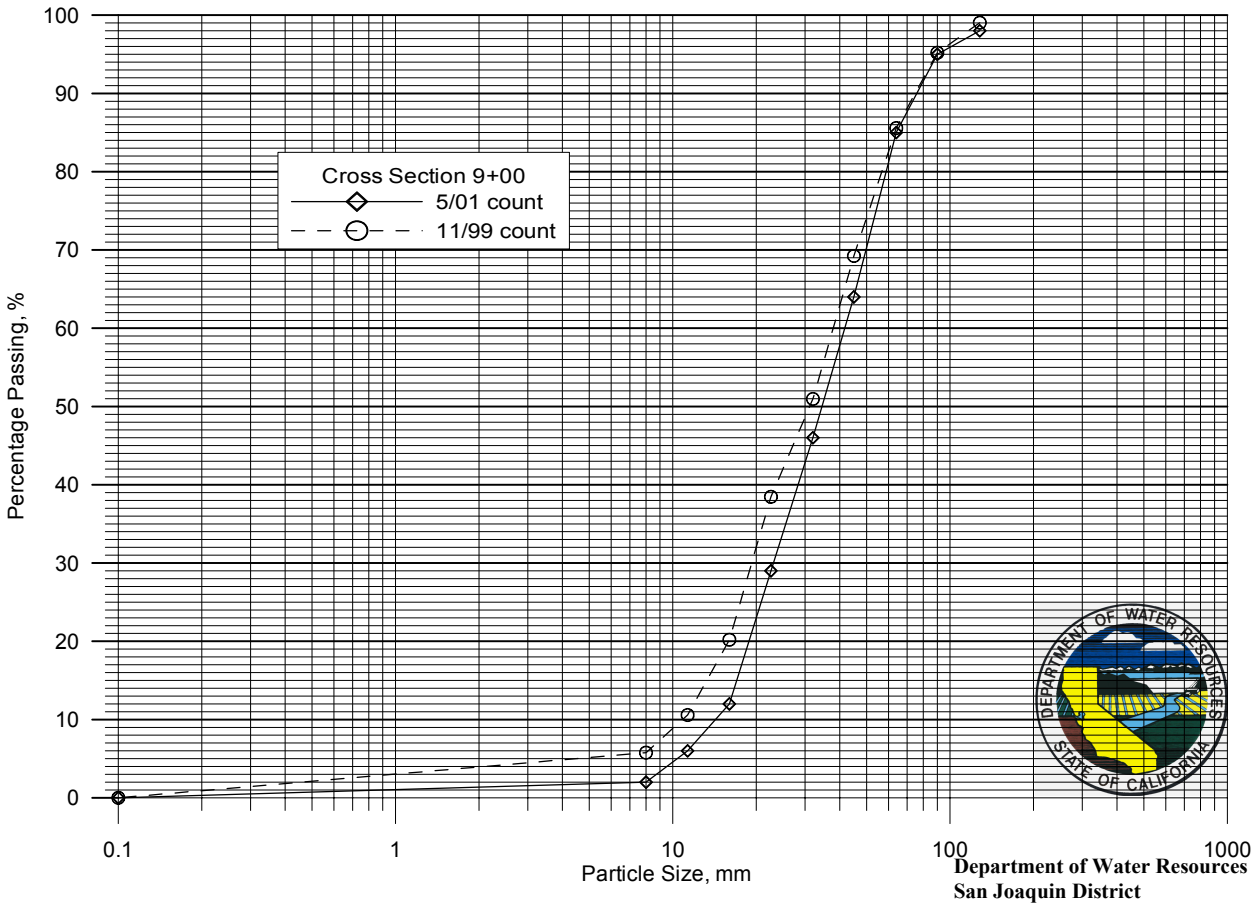
Appendix D

Pebble Counts

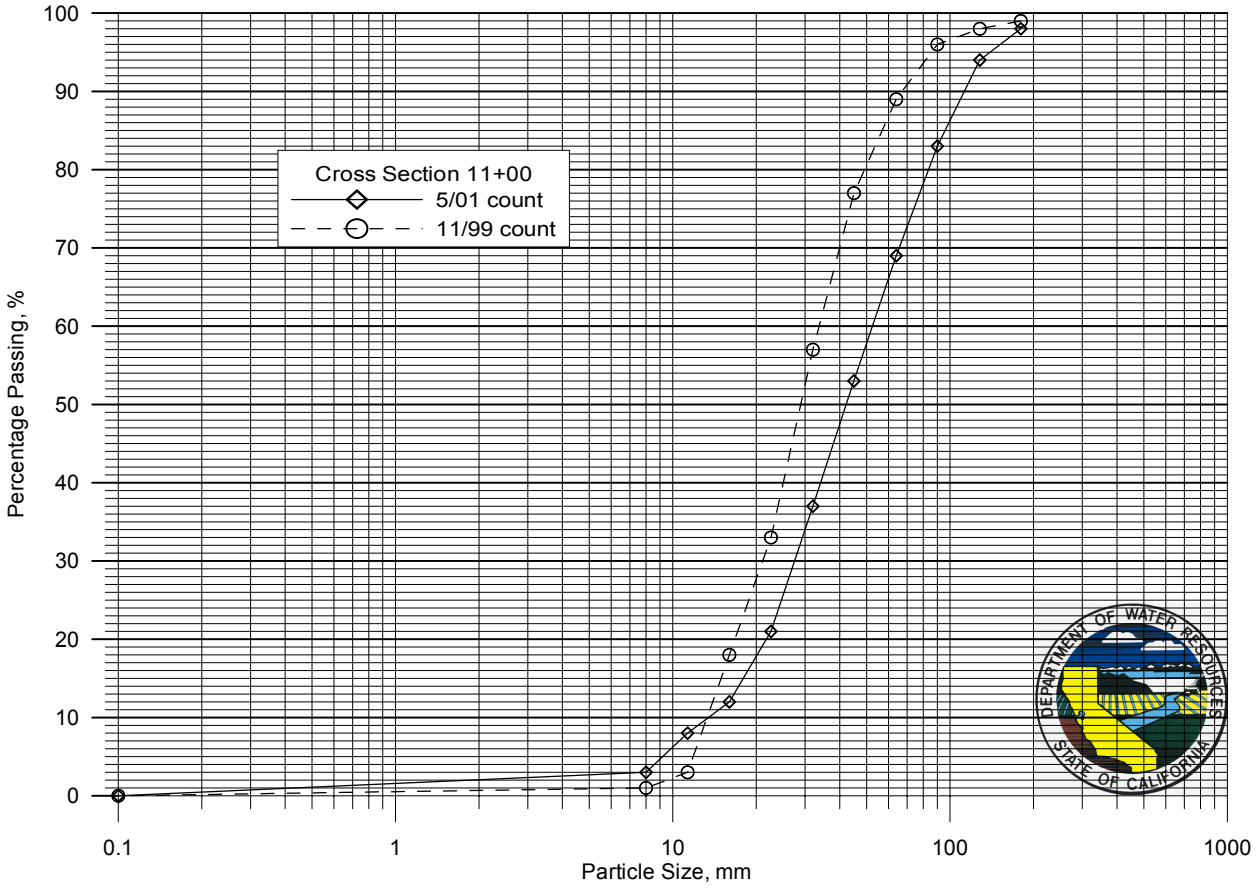
Ratzlaff Reach - Monitoring Pebble Count Analysis



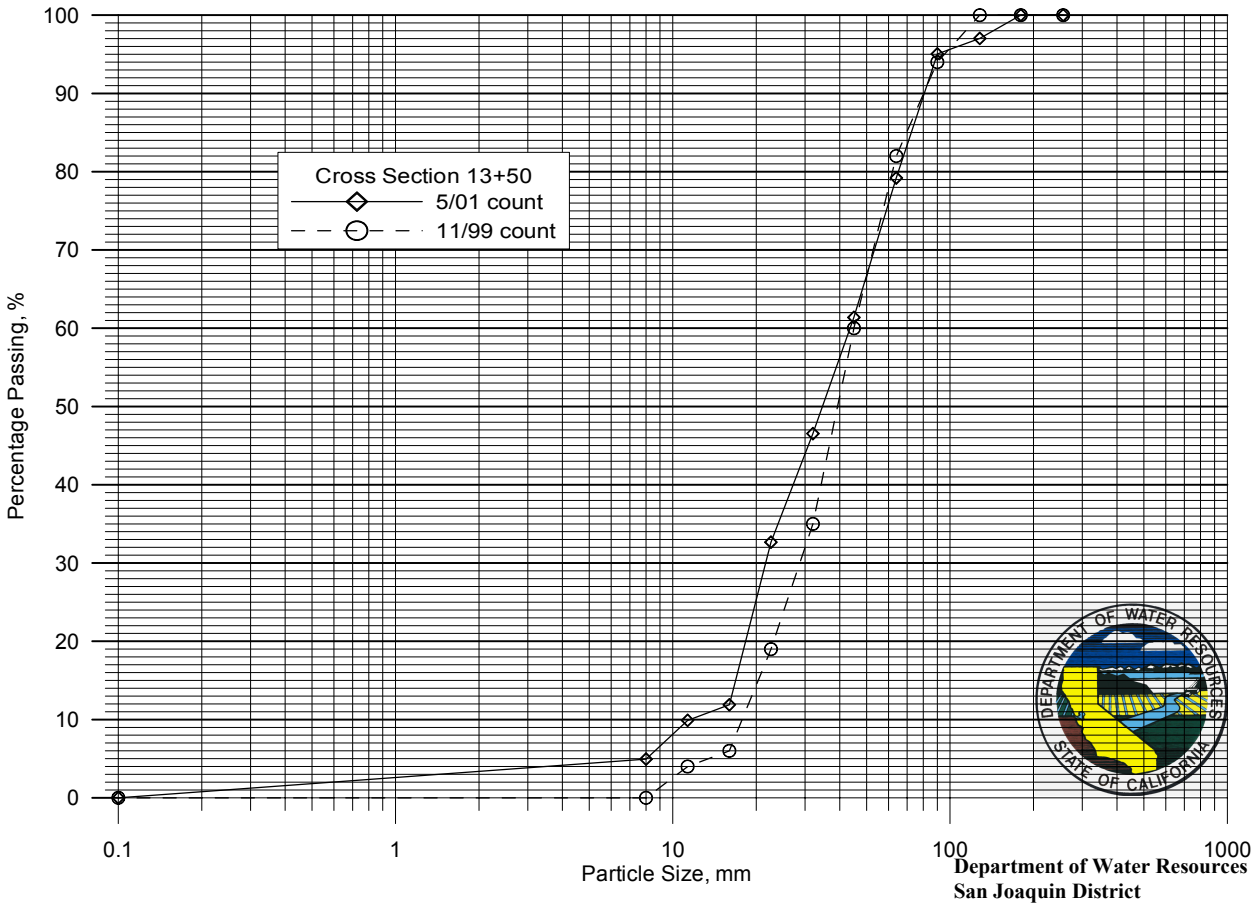
Ratzlaff Reach - Monitoring Pebble Count Analysis



Ratzlaff Reach - Monitoring Pebble Count Analysis



Ratzlaff Reach - Monitoring Pebble Count Analysis



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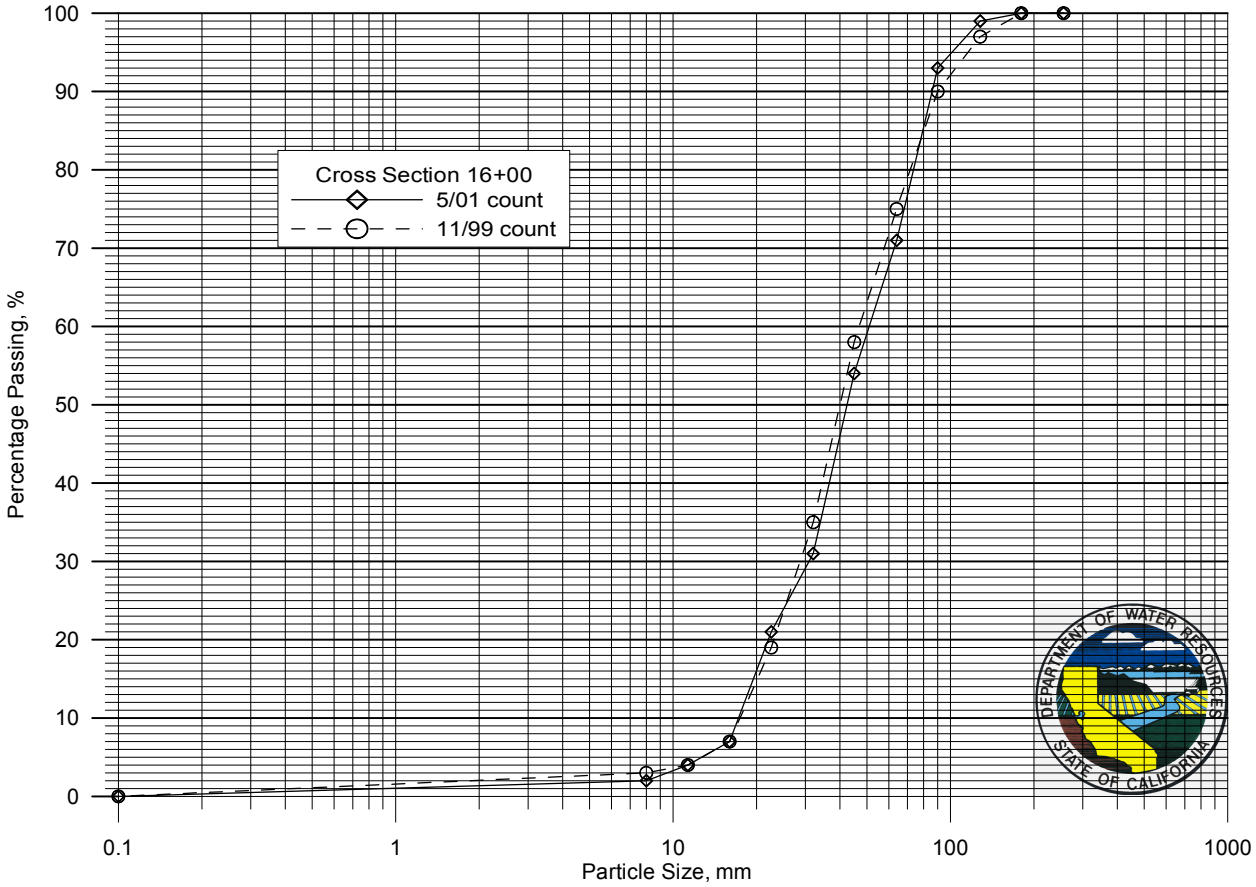
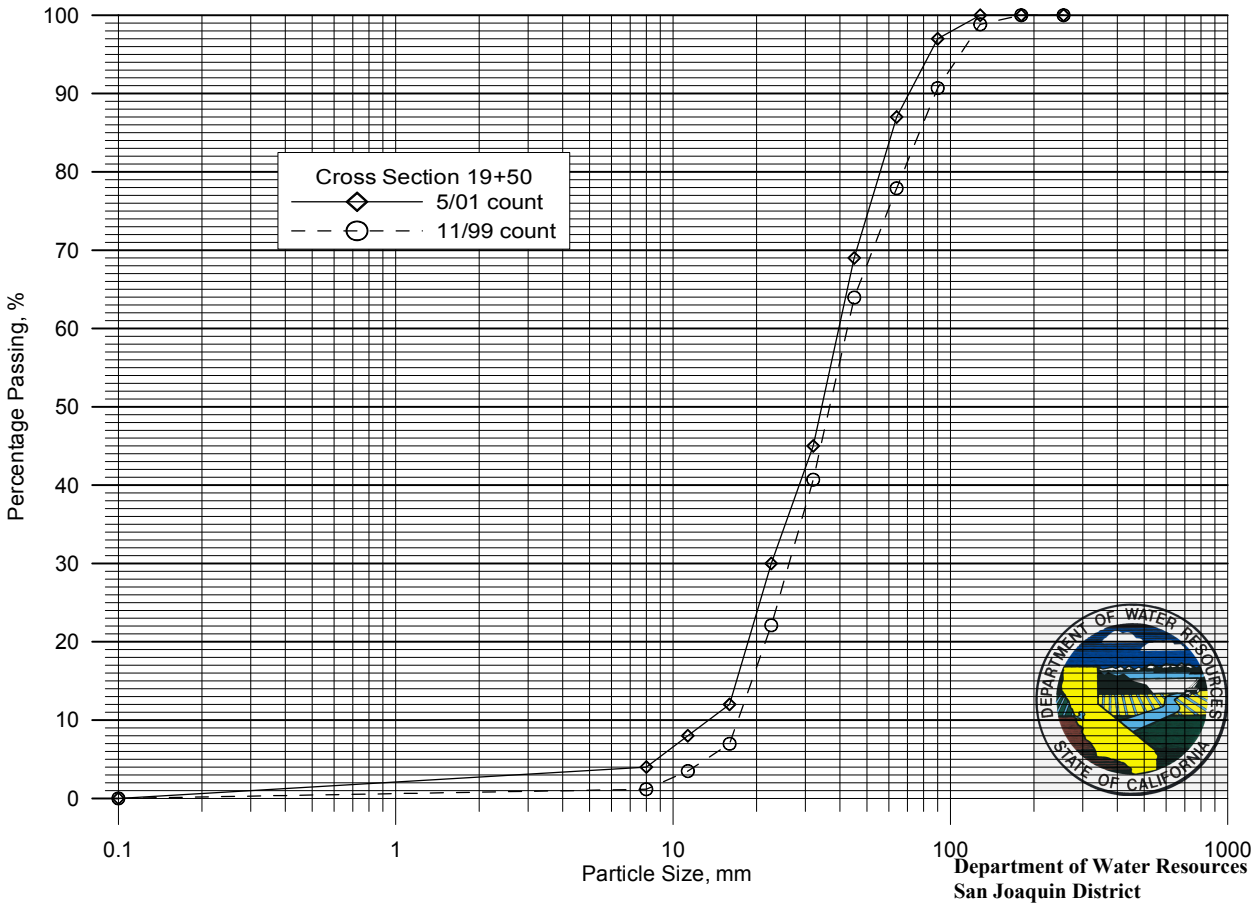
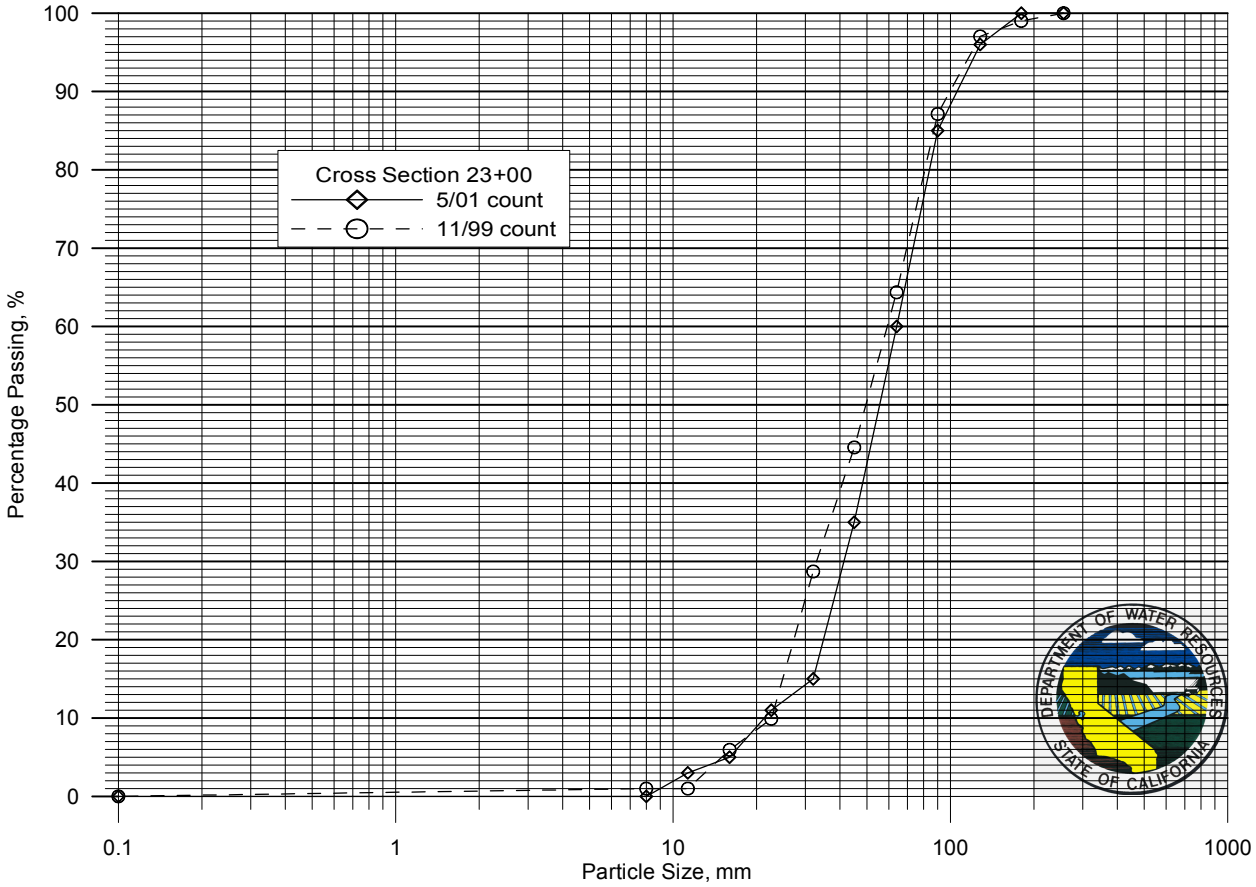
Ratzlaff Reach - Monitoring Pebble Count Analysis



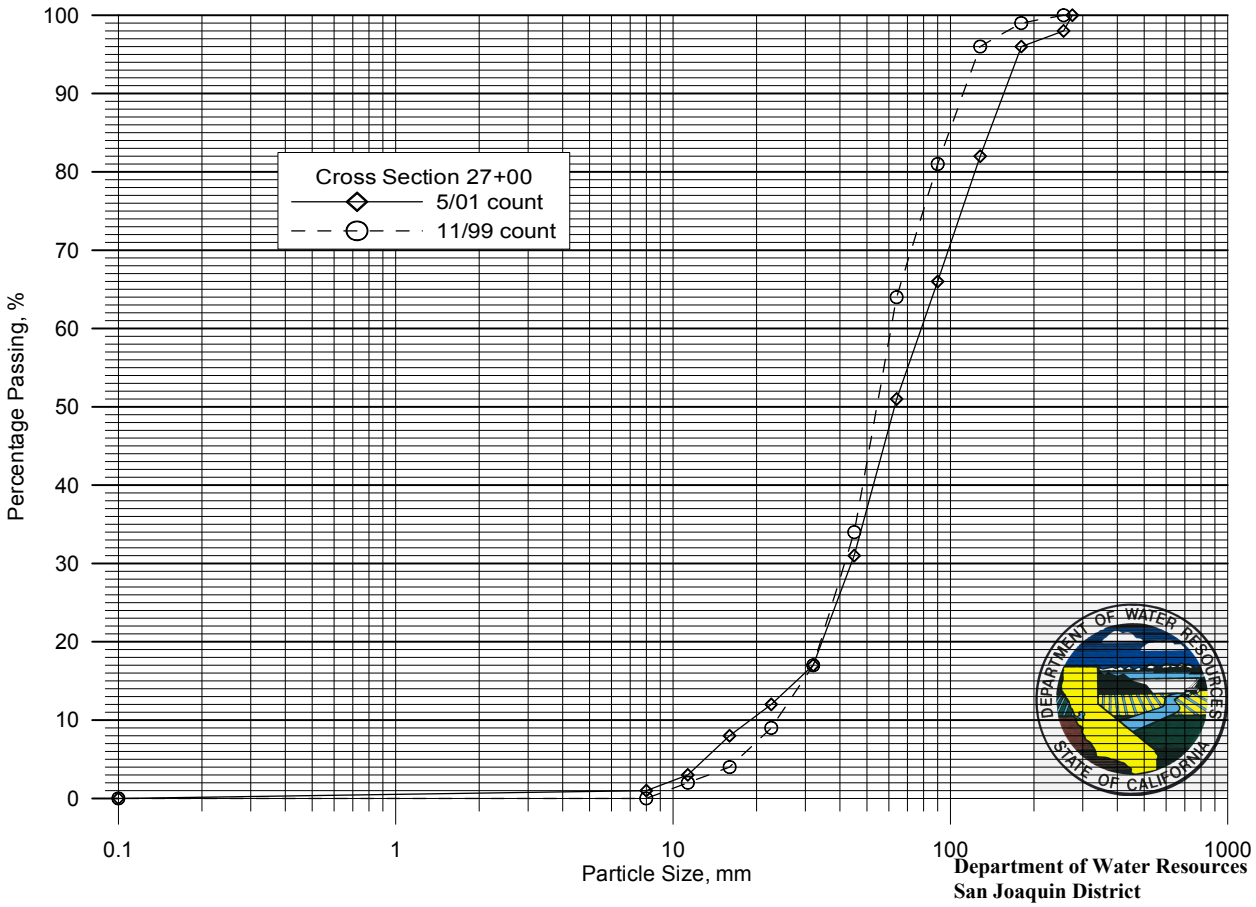
Ratzlaff Reach - Monitoring Pebble Count Analysis



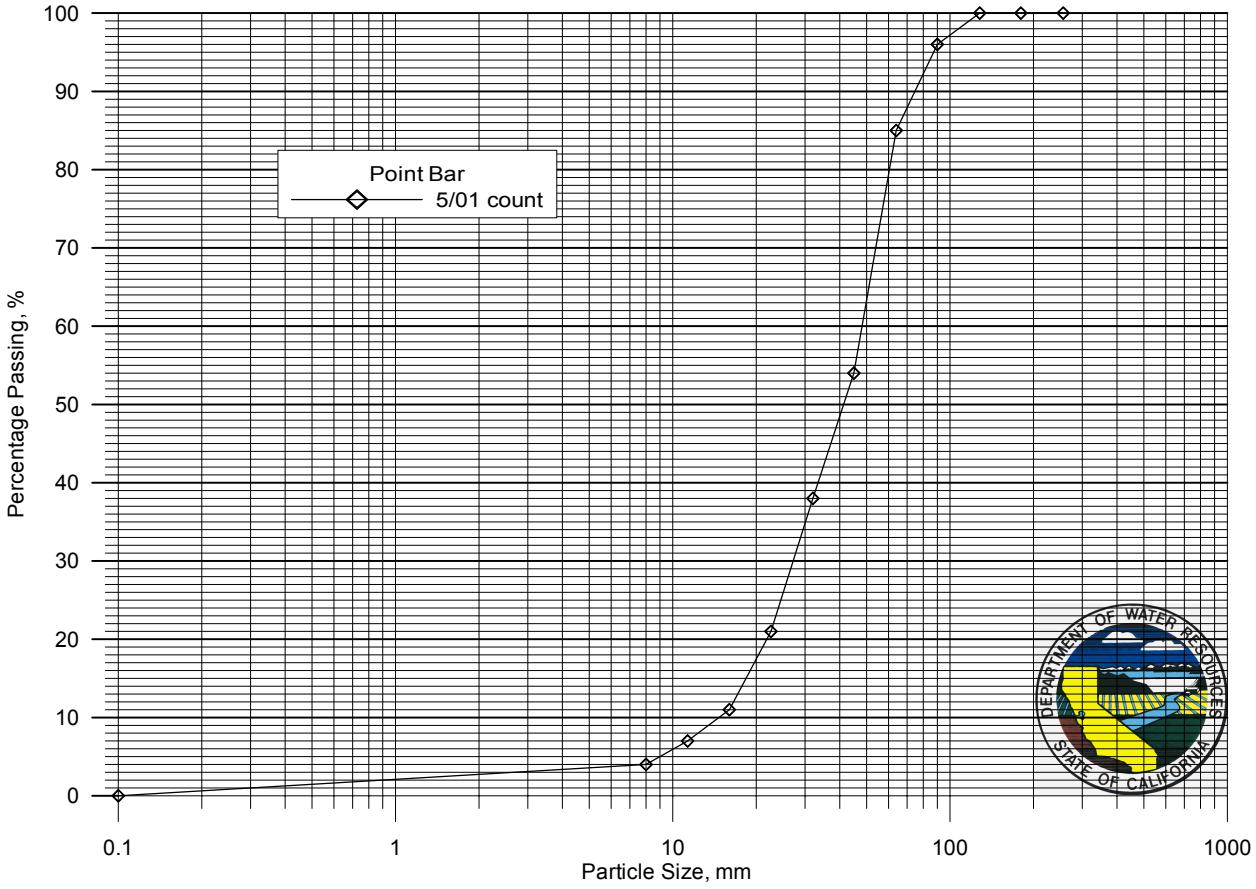
Ratzlaff Reach - Monitoring Pebble Count Analysis



Ratzlaff Reach - Monitoring Pebble Count Analysis



Ratzlaff Reach - Monitoring Pebble Count Analysis



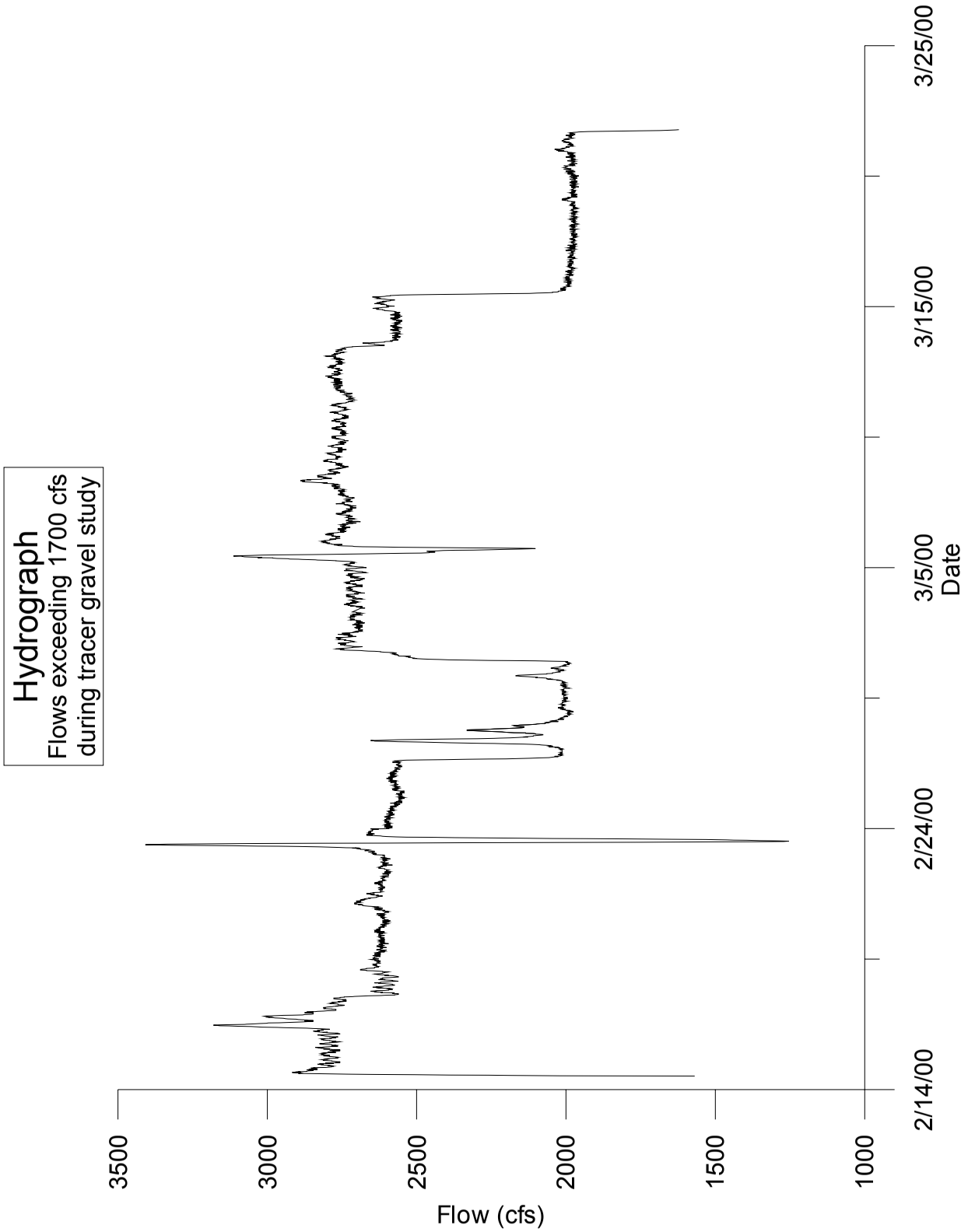
Appendix E

HEC-RAS Results

		Elevations (ft)			
		Q=2594		Q=1686	
Design Station	Model Station	Obs WS 2/25/2000	Model W.S. Elev	Obs WS 4/26/2000	Model W.S. Elev
1+00	270	174.02	173.75	172.56	172.74
	260		173.47		172.42
5+00	250	173.41	173.20	171.78	172.09
	245		173.10		172.00
	240		173.05		171.95
	235		172.89		171.81
11+00	230	172.89	172.77	171.38	171.71
	225		172.69		171.63
	220		172.61		171.55
	215		172.61		171.53
	210		172.60		171.52
16+00	207	172.37	172.56	171.44	171.47
	205		172.45		171.40
	200		172.32		171.30
	180		172.04		171.06
	170		171.88		170.92
23+00	160	171.81	171.62	170.50	170.69
	140		171.26		170.34
27+00	120	171.10	170.78	169.59	169.88
	100		170.48		169.49
	95		170.51		169.52
	92		170.25		169.31
	90		170.18		169.24
below reach	84	170.04	169.38	168.33	168.52

Appendix F

Hydrograph



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